Co Op Agreement
Idaho Department
of Health &
Welfare

SEDIMENT MONITORING TECHNIQUES
VALIDATION YEAR 2

Coop Agreement
Idaho Dept.
of Health
and Welfare

PROGRESS REPORT

SEDIMENT MONITORING TECHNIQUES VALIDATION

Year 2

Prepared for

Idaho Department of Health and Welfare
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CHINOOK SALMON INCUBATION STUDIES

INTRODUCTION

The Idaho Health and Welfare Department has developed field techniques to measure the effects of sediment on beneficial uses of streams. One of these techniques, artificial redd monitoring, has been used to assess the condition of salmonid spawning sites. This measure has not had the necessary validation to demonstrate whether it is appropriate for quantifying sediment effects on spawning habitats. This report describes the progress made during the second year of a multi-year project toward the validation of artificial redd monitoring techniques.

In April, 1990, we began research to evaluate artificial redd monitoring as a technique to measure the effect of fine sediment on beneficial uses of streams. During the initial studies, we investigated steelhead trout redds in the mainstem Salmon River (King and Thurow 1990). In August 1990, we began similar investigations of chinook salmon redds in the South Fork Salmon River. We selected four types of sampling sites: natural chinook salmon redds, artificially constructed redds, sites in undisturbed (natural) substrate surrounding redds, and sites with artificially cleaned substrate. We measured physical parameters including water depths and velocities, intragravel dissolved oxygen, intragravel velocity, and particle size distribution. This report describes the chinook salmon incubation studies. In April 1991, we initiated a third incubation study of Yellowstone cutthroat trout in a sedimentary geologic type in Eastern Idaho. A report describing the cutthroat trout research will be prepared in 1992.

OBJECTIVES

1. To measure temporal changes in fine sediment, intragravel dissolved oxygen, egg and alevin survivial in natural and artificial redds.

2. To determine if differences in the above referenced parameters between natural and artificial redds are statistically significant.

DESCRIPTION OF STUDY AREA

Study reaches were selected in a chinook salmon (Oncorhynchus tshawytscha) spawning area on the South Fork Salmon River (SFSR). The study reaches lie within Poverty Flat near the confluence of Blackmare Creek (Figure 1). From its origin, the river flows north and joins the mainstem Salmon River 7.7 km upstream from Riggins, Idaho. The SFSR flows through the Central Idaho batholith, an area of granitic bedrock. At lower elevations, the bedrock is highly weathered and results in very erodable soils. Transport of erodable, sand-sized material as bedload has effected the stream channel and substrate. Peak stream discharge typically occurs in a six week period in May and June during snowmelt. Base flows occur from September through January.

Historically, the South Fork Salmon River was the single most important summer chinook salmon spawning stream in the Columbia River basin (Mallet 1974). Since the 1940's, human activities in the drainage have caused erosion of unstable soils and damage to the aquatic resources (Megahan et al. 1980). As a consequence of severe habitat degradation and the simultaneous effects of hydroelectric development on the Snake and Columbia Rivers, the chinook salmon population declined severely. Hatchery-reared chinook salmon have been introduced to supplement wild populations.

METHODS

We selected sites within and adjacent to chinook salmon redds in the Poverty Flat reach. Chinook salmon spawned in three main reaches and study redds were clustered in each reach (Figure 2). On August 27, we randomly selected ten chinook salmon redds at each of the three reaches for a total of 30 redds.

In Reach 1, we inserted probes (described by Burton et al. 1990) into ten redds

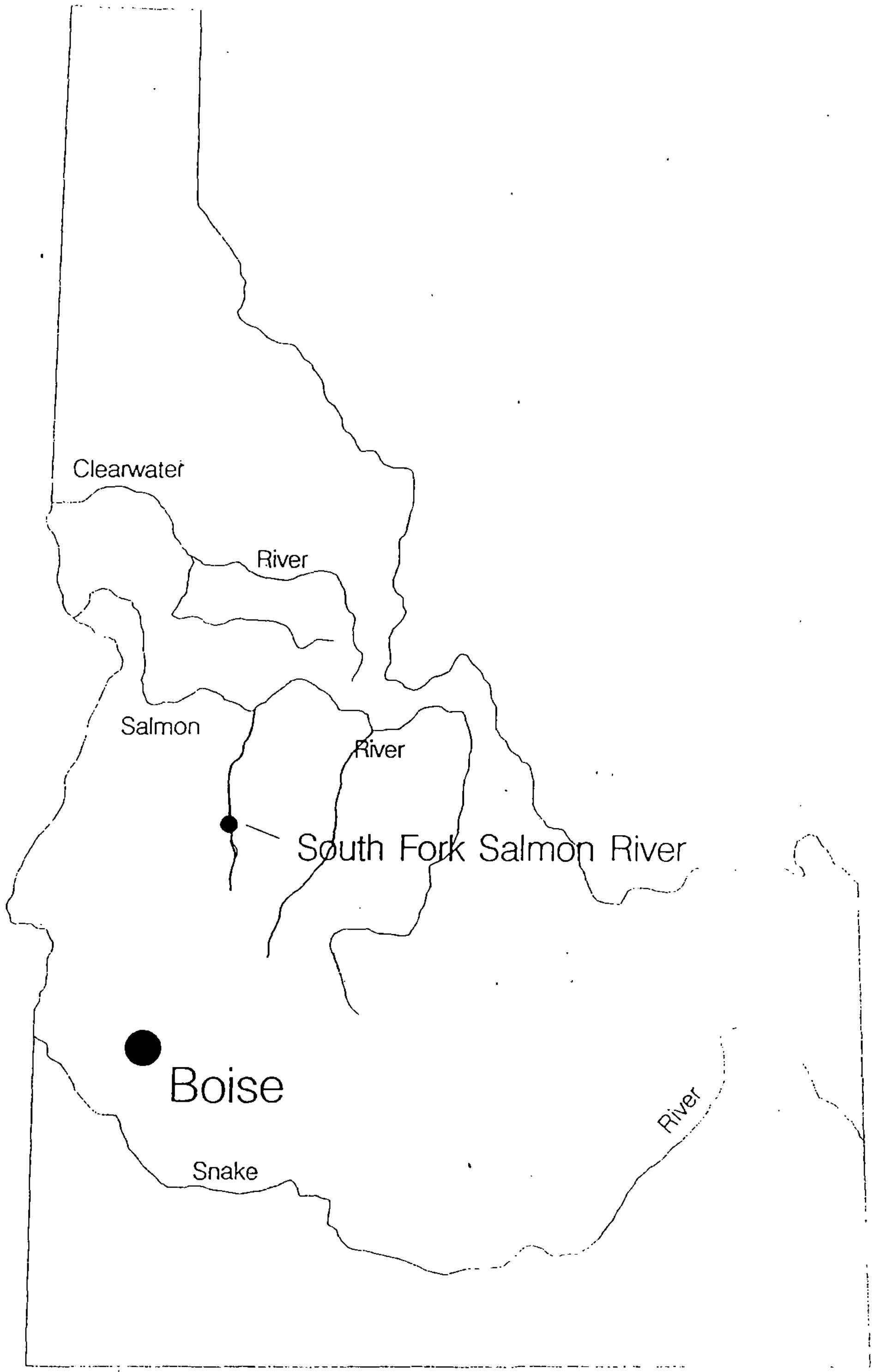


Figure 1. South Fork Salmon River drainage, Idaho

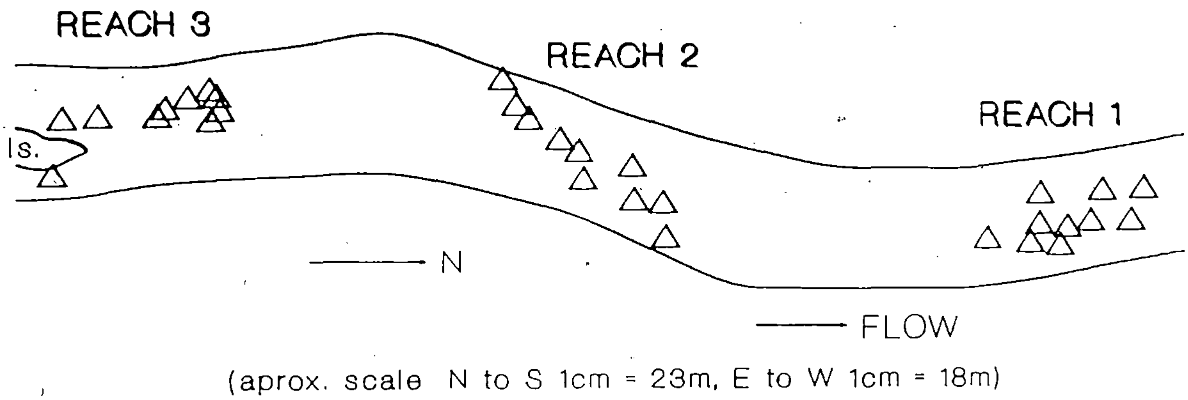


Figure 2. The location of reaches and individual redds at the Poverty Flats spawning site.

from the downstream end of the pit and at the boundary of the undisturbed substrate and tailspill. We attempted to insert probes into the egg pocket. Adjacent to each redd, we established additional paired sampling sites for: (1) construction of artificial redds, (2) sampling natural substrate surrounding the redd, and (3) measuring the intrusion rate of fine sediments into substrate cleaned of fines less than 6.35 mm. On August 28, two artificial redds were constructed adjacent to each natural redd. We obtained water-hardened chinook salmon eggs from the Idaho Department of Fish and Game's spawning facility on the SFSR and inserted 100 into one artificial redd at each of the ten sites. The other ten artificial redds did not receive eggs and were paired with the artificial redds containing eggs. Natural substrate sites and intrusion sites were selected and marked adjacent to each natural redd. We also buried a probe in the undisturbed substrate.

In reaches 2 and 3, we did not insert probes into the natural redds, but we established additional sampling sites adjacent to each redd. We constructed artificial redds but did not insert eggs, and selected natural substrate and intrusion sites. We buried one probe in the undisturbed substrate in each of the two reaches and inserted probes into all twenty artificial redds.

Selected physical measurements were made of all the natural and artificial redds to characterize similarities and differences between redd types and to determine variability. Parameters measured included the depth of water over the tailspill, the depth of water over the pit, pit width and length, tailspill width and length, and stream velocity over the pit and tailspill at a depth 0.6 times the total depth. Measurements made at the natural redds, artificial redds, natural substrate and sediment intrusion sites included the initial stream depth and stream velocity. Velocity measurements were made with a Marsh-McBirney current meter.

The dissolved oxygen content of water within the natural and artificial redds and undisturbed substrate was sampled at intervals during incubation. Sampling dates were September 11, October 23, December 6, February 13, March 4, April 8, April 25, and May 13. We extracted water samples from the probes through the flexible tubing with a hand activated vacuum pump. Approximately 250ml of water was initially extracted to cleanse the probe and measure the water temperature. A second extraction was used to fill a 300 ml BOD bottle. Dissolved oxygen content was determined in the field using the modified Winkler procedure. Percent saturation was determined using standard procedures to correct for water temperature and elevation.

The probes were also used to determine an index of the intergravel velocity within the natural and artificial redds. These determinations were made on those artificial and natural redds just prior to freeze coring and all artificial redds without eggs, usually one day prior to the dissolved oxygen sampling date. A thin tube was inserted through the flexible tube on the dissolved oxygen probe and into the probe itself. A 50 ml sample of water was extracted using a syringe and the specific conductance of the water was measured. Next, 50 ml of 0.05M NaCl solution was injected into the probe. Fifty ml samples were extracted at 2 and 5 minutes intervals and the specific conductance was measured. Samples were placed in vials and frozen for later laboratory determination of sodium and chloride concentrations. The dilution rate of the sodium concentration of the samples extracted at 2 and 5 minutes can be used as an index of the apparent velocity within the substrate. Laboratory analysis of the sodium and chloride concentrations is not completed and results relating to the index of intergravel velocity will be reported at a later time.

We collected substrate samples to characterize the particle size distibution in the sampling sites. In reaches 2 and 3, we randomly selected five artificial redds and five paired natural substrate sites for freeze coring on October 23, March 6, April 8, and April 25. Five intrusion sites paired with the artificial redds were extracted on each date. A tri-tube freeze coring procedure using liquid CO2 (Everest, et al. 1980) was used to extract a vertical substrate sample from the artificial redds and at the surrounding substrate.

In Reach 1, we did not core sites until emergence of chinook salmon fry was complete. We calculated temperature units and estimated the timing of fry emergence. On May 1, immediately prior to predicted emergence, we capped the artificial redds containing eggs using the net described by Burton et al. (1990). Numbers of emergent fry were counted and released. We calculated the percent survival of fry in each capped artificial redd. Data from redd capping studies suggests that 90% emergence of fry typically occurs within approximately 14 days (Johnson et al. 1978, Thurow 1987). We began coring the ten natural redds and their paired sites on May 14.

Using definitions proposed by Young et al. (1989), we labelled cores as egg-pocket samples if we observed eggs or alevins in the core. The samples were laid horizontally on a sheet metal tray and subsampled into 10 cm strata. A propane torch facilitated the melting process. The sediment core samples were air dried and sieved through the following mesh sizes: 128, 64, 32, 16, 9.5, 8, 6.35, 4, 2, 1, 0.85, 0.5, ,0.25, 0.125, and 0.063 mm. We calculated four indices to relate sediment composition to other redd parameters including: the percentage of material less than 6.35 mm, the percentage of material less than 0.85 mm, the Fredle index (Lotspeich and Everest 1981) and the geometric mean diameter. These indices were determined for the individual vertical substrata and for the composite freeze core. Since the freeze core technique did not work well for the instrusion site, these indices were calculated for the total sample extracted in the collapsible bucket.

The bias associated with very large particles has been recognized and many workers have excluded them from analysis (Adams and Beschta 1980, Tappel and Bjornn 1983). We observed larger particles being lost as our cores were extracted. To avoid bias, we excluded particles larger than 64 mm from our analysis. As Kondolf (1988) observed, where the percentage of fine sediment is to be compared among sites or sampling times, the sample can be computed based on the truncated distribution. Stowell et al. (1983) defined fines as particles smaller than 6.35 mm and used the percent fines as an index of gravel quality in the Idaho batholith. We adopted their definition.

We used SAS/STAT for personal computers, version 6, to calculate statistics and conduct statistical tests. We were especially interested in detecting differences between sample types: natural redds, artificial redds both with and without eggs, natural substrate and intrusion sites. However, parameter values may also be affected by the stream reach, the sampling date, and in the case of the core samples, the depth strata. Generally, an analysis of variance was conducted to determine if there were significant influences caused by reach, date or strata and the results were used as a basis for either pooling data or stratifying data. Differences in the means of parameters for the pooled or stratified data were tested using a Duncan's multiple range test or a t-test.

We examined differences in initial conditions of sampling sites by reach and type of site. Differences in dissolved oxygen were tested for by reach and sample site and we also evaluated temporal changes. We examined differences in sediment composition between reaches, sites, vertical strata, and we tested temporal changes. We compared conditions in natural and artificial redds by examining differences in initial conditions, surface morphology, water velocity, dissolved oxygen concentration, apparent velocity, temperature, and substrate composition. We evaluated relationships between initial substrate composition and final redd conditions, redd morphology and dissolved oxygen, redd morphology and substrate composition, dissolved oxygen and substrate composition, and temperature and dissolved oxygen. We accepted an alpha of 0.05 as the level of significance. Where statistical tests are discussed, this level of significance is applied unless another level is specified within the text.

RESULTS

Compiled data are displayed in this section of the Report. Because research is continuing, this information should be considered preliminary. We have made no attempt to thoroughly analyze the data or present complete results. If trends are

apparent, we have attempted to illustrate them. Thorough compilation of the information, statistical analysis, correlation of variables, and discussion of results will be presented in a future report and publications.

Initial Physical Conditions

Initial physical conditions were used to describe the sites chinook salmon selected for redd construction, and the characteristics of the completed redds. Data from natural redds were used to select study sites for constructing artificial redds, evaluating natural undisturbed substrate, and measuring intrusion rates of fine sediment.

Chinook salmon spawned in a range of depths in the study reaches and the physical conditions varied between the three study reaches. Water depths immediately upstream from natural redds ranged from 24 to 51 cm and averaged 34.5 cm (Table 1). Reach 1 was characterized by alternating deep water areas and mounds or windrows of gravel and many of the natural redds were constructed at the leading edge of the gravel mounds. We were able to locate adjacent deep water areas for artificial redds with eggs and natural substrate sites but artificial redds without eggs and the intrusion sites were located in significantly shallower sites. Reach 2 was deeper than Reach 3 but did not exhibit gravel mounds as prevalently as Reach 1. There was no significant difference in the depth of study sites within Reach 2. Natural redds and other study sites were located at significantly shallower depths in Reach 3 as compared to Reaches 1 and 2. Many of the natural redds in Reach 3 were located in a broad riffle. There were no statistically significant differences in the depths of study sites within Reach 3.

Depths and velocities in natural chinook salmon redds were very similar between the three reaches even though the physical conditions in the reaches differed. Although depths immediately upstream from the redds were significantly shallower in Reach 3, the water velocity at that location and the depths and velocities measured in the pit, at one third the length of the tailspill, and at the top of the tailspill were not significantly different between reaches (Table 2).

Artificially constructed redds exhibited much more variability in depths and velocities than we observed in natural redds. Depths and velocities tended to be largest in Reach 2 and smallest in Reach 1 (Table 3). With the exception of the velocity measured at one third the length of the tailspill, all measured depths and velocities differed significantly between reaches.

Our ability to mimic conditions in natural redds was variable. Within Reaches 1 and 2, locations in artificial redds were generally deeper with lower velocities than we observed in natural redds (Table 3). Within Reach 1 in redd pits, depths were significantly larger and velocities significantly less in artificial redds as compared to natural redds. In Reach 2 in redd pits and at the top of the tailspills, depths were significantly larger and velocities significantly less in artificial redds. Conditions at the other locations in the redd were similar. In Reach 3, the pit depths and the velocities at one third the length of the tailspill were similar. Depths and velocities at all other sites within the redd were significantly shallower with lower velocities in the artificial redds as compared to natural redds.

Unlike measured depths and velocities, dimensions of natural redds were not similar between reaches. The length of redd pits and tailspills were significantly shorter in Reach 3 as compared to reaches 1 and 2 and redd pits and tailspills were significantly wider in Reach 1 as compared to reaches 2 and 3 (Table 4). Dimensions of artificial redds followed a similar trend although pit widths and tailspill lengths were not significantly different between reaches.

Although artificial redds were more uniform in size than natural redds, they did not closely mimic natural redd dimensions (Table 4). In Reach 1, artificial redds were significantly smaller than natural redds except in tailspill length. In Reach 2 artificial redds were also significantly smaller except in pit width and

Table 1. Water depth in cm immediately upstream of the corresponding sample site. Poverty Flat spawning area, South Fork Salmon River, September 11, 1990.

NATURAL REDDS		ARTIFICIAL REDDS WITH EGGS		ARTIFICIAL REDDS NO EGGS		INTRUSION SITES		NATURAL SUBSTRATE	
Site	Depth	Site	Depth	Site	Depth	Site	Depth	Site	Depth
REACH 1									
PR1	28	A1	32	AN1	30	I1	26	S1	34
PR2	43	A2	33	AN2	30	I2	20	S2	20
PR3	27	A3	20	AN3	18	I3	26	S3	31
PR4	43	A4	38	AN4	43	I4	37	S4	37
PR5	41	A5	22	AN5	18	I5	22	S5	21
PR6	35	A6	22	AN6	18	I6	19	S6	36
PR7	28	A7	21	AN7	21	I7	25	S7	27
PR8	44	A8	43	AN8	27	I8	21	S8	22
PR9	42	A9	21	AN9	15	I9	20	S9	30
PR10	43	A10	45	AN10	41	I10	40	S10	39
MEAN	37.4		29.7		26.1		25.6		29.7
ST. DEV.	6.8		9.274		9.406		6.916		6.604
REACH 2									
PR11	27			AN11	43	I11	40	S11	31
PR12	37			AN12	34	I12	27	S12	28
PR13	35			AN13	28	I13	26	S13	31
PR14	31			AN14	31	I14	30.	S14	28
PR15	33			AN15	36	I15	33	S15	27
PR16	51			AN16	49	I16	46	S16	44
PR17	40			AN17	41	I17	40	S17	41
PR18				AN18	34	I18	34	S18	32
PR19	41			AN19	40	I19	38	S19	35
PR20	46			AN20	37	I20	46	S20	40
MEAN	37.9				37.3		36		33.7
ST. DEV.	7.078				5.831		6.826		5.728
REACH 3									
PR21				AN21	22	I21	20	S21	21
PR22	24			AN22	21	I22	22	S22	22
PR23	26			AN23	28	I23	27	S23	26
PR24	24			AN24	23	I24	29	S24	28
PR25	24			AN25	24	I25	23	S25	24
PR26				AN26	21	I26	23	S26	19
PR27				AN27	18	I27	18	S27	18
PR28	24			AN28	18	I28	20	S28	24
PR29	25			AN29	15	I29	17	S29	21
PR30				AN30	21	I30	17	S30	21
MEAN	24.5				21.1		21.6		22.4
ST. DEV.	0.764				3.419		3.852		2.939
GR. MEAN	34.48		29.74		28.22		27.73		28.6
ST. DEV.	14.897		9.274		9.385		8.559		7.08
N	25		10		30		30		30

Table 2. Water depths (cm) amd velocities (m/s) at locations in chinook salmon redds. Poverty Flat spawning area, South Fork Salmon River, September 11, 1990

REDD	ABOVE PIT		BOTTOM PIT		"1/3 TAILSPILL		TOP TAILSPILL	
	Depth	Velocity	Depth	Velocity	Depth	Velocity	Depth	Velocity
REACH 1								
PR1	24.384	0.68	36.576	0.3	27.432	0.44	18.288	0.61
PR2	38.1	0.33	39.624	0.46	21.336	0.63	18.288	0.72
PR3	35.052	0.26	36.576	0.24	18.288	0.37	9.144	0.5
PR4	44.196	0.38	47.244	0.33	32.004	0.35	12.192	0.58
PR5	41.148	0.35	45.72	0.37	30.48	0.45	15.24	0.7
PR6	38.1	0.47	39.624	0.36	33.528	0.37	12.192	0.68
PR7	24.384	0.34	32.004	0.24	18.288	0.39	12.192	0.54
PR8	38.1	0.29	39.624	0.31	25.908	0.47	15.24	0.66
PR9	42.672	0.24	50.292	0.19	27.432	0.41	15.24	0.6
PR10	44.196	0.34	45.72	0.3	41.148	0.33	33.528	0.35
MEAN	37.0332	0.368	41.3004	0.31	27.5844	0.421	16.1544	0.594
ST. DEV.	6.918691	0.120565	5.428949	0.073075	6.796767	0.081786	6.4008	0.105186
REACH 2								
PR11	33.528	0.36	35.052	0.44	19.812	0.5	13.716	0.6
PR12	35.052	0.44	39.624	0.25	30.48	0.35	13.716	0.54
PR13	35.052	0.52	39.624	0.49	30.48	0.41	21.336	0.59
PR14	27.432	0.4	35.052	0.3	24.384	0.31	15.24	0.65
PR15	33.528	0.58	38.1	0.5	32.004	0.57	21.336	0.6
PR16	44.196	0.4	47.244	0.31	33.528	0.43	21.336	0.5
PR17	38.1	0.46	41.148	0.48	33.528	0.52	27.432	0.62
PR18	35.052	0.34	41.148	0.29	28.956	0.27	13.716	0.33
PR19	38.1	0.5	42.672	0.5	30.48	0.47	18.288	0.69
PR20	35.052	0.31	42.672	0.36	28.956	0.48	18.288	0.67
MEAN	35.5092	0.431	40.2336	0.392	29.2608	0.431	18.4404	0.579
ST. DEV.	4.035004	0.081049	3.488595	0.094742	4.020588	0.091373	4.280786	0.09904
REACH 3								
PR21	41.148	0.38	45.72	0.41	27.432	0.44	15.24	0.7
PR22	21.336	0.41	30.48	0.22	24.384	0.26	18.288	0.44
PR23	22.86	0.43	35.052	0.29	25.908	0.39	19.812	0.5
PR24	24.384	0.46	36.576	0.39	25.908	0.42	18.288	0.59
PR25	22.86	0.42	36.576	0.15	19.812	0.21	16.764	0.46
PR26	36.576	0.35	44.196	0.44	35.052	0.48	30.48	0.6
PR27	39.624	0.35	42.672	0.26	30.48	0.33	18.288	0.49
PR28	21.336	0.48	32.004	0.33	24.384	0.41	12.192	0.67
PR29	21.336	0.4	33.528	0.22	22.86	0.32	10.668	0.69
PR30	30.48	0.41	38.1	0.37	22.86	0.41	13.716	0.61
MEAN	28.194	0.409	37.4904	0.308	25.908	0.367	17.3736	0.575
ST. DEV.	7.658005	0.040112	4.924195	0.090532	4.089321	0.080505	5.199498	0.091788
GR. MEAN	33.5788	0.402667	39.6748	0.336667	27.5844	0.406333	17.3228	0.582667
ST. DEV.	7.471055	0.090845	4.953716	0.095056	5.313641	0.089237	5.445087	0.09916

Table 3. Water depths (cm) amd velocities (m/s) at locations in artificially constructed redds. Poverty Flat spawning area, South Fork Salmon River, September 11, 1990.

REDD	ABOVE PIT Depth	ABOVE PIT Velocity	BOTTOM PIT Depth	BOTTOM PIT Velocity	"1/3 TAILSPILL Depth	"1/3 TAILSPILL Velocity	TOP TAILSPILL Depth	TOP TAILSPILL Velocity
REACH 1								
A1	30.48	0.58	53.34	0.18	27.432	0.6	16.764	0.71
A2	30.48	0.2	51.816	0.11	30.48	0.24	12.192	0.47
A3	12.192	0.25	32.004	0.09	16.764	0.27	9.144	0.48
A4	36.576	0.23	54.864	0.1	36.576	0.27	24.384	0.35
A5	33.528	0.31	42.672	0.3	19.812	0.47	10.668	0.58
A6	33.528	0.22	48.768	0.17	21.336	0.38	12.192	0.66
A7	22.86	0.27	33.528	0.28	16.764	0.39	12.192	0.5
A8	42.672	0.2	64.008	0.11	36.576	0.31	24.384	0.43
A9	48.768	0.19	57.912	0.24	21.336	0.35	12.192	0.46
A10	42.672	0.33	57.912	0.24	38.1	0.34	38.1	0.27
MEAN	33.3756	0.278	49.6824	0.182	26.5176	0.362	17.2212	0.491
ST. DEV.	9.980746	0.110164	10.04454	0.074806	8.012241	0.102255	8.649287	0.125893
REACH 2								
AN11	47.244	0.31	59.436	0.26	50.292	0.41	27.432	0.51
AN12	30.48	0.44	48.768	0.24	25.908	0.4	19.812	0.49
AN13	50.292	0.38	57.912	0.41	28.956	0.55	12.192	0.7
AN14	33.528	0.61	50.292	0.42	33.528	0.53	22.86	0.55
AN15	39.624	0.28	54.864	0.27	30.48	0.44	22.86	0.52
AN16	42.672	0.39	57.912	0.38	33.528	0.43	28.956	0.43
AN17	39.624	0.44	57.912	0.22	33.528	0.48	30.48	0.47
AN18	32.004	0.28	54.864	0.2	30.48	0.25	25.908	0.26
AN19	35.052	0.46	45.72	0.35	32.004	0.51	25.908	0.52
AN20	47.244	0.57	62.484	0.5	33.528	0.68	27.432	0.67
MEAN	39.7764	0.416	55.0164	0.325	33.2232	0.468	24.384	0.512
ST. DEV.	6.623704	0.10707	4.982804	0.095734	6.164199	0.107313	5.054536	0.115914
REACH 3								
AN21	22.86	0.26	38.1	0.12	19.812	0.29	7.62	0.47
AN22	25.908	0.3	42.672	0.16	12.192	0.37	10.668	0.39
AN23	21.336	0.38	38.1	0.15	18.288	0.42	21.336	0.41
AN24	32.004	0.36	38.1	0.2	15.24	0.61	18.288	0.47
AN25	21.336	0.34	42.672	0.02	18.288	0.33	10.668	0.38
AN26	22.86	0.36	33.528	0.24	16.764	0.39	13.716	0.37
AN27	19.812	0.32	39.624	0.04	16.764	0.21	9.144	0.28
AN28	19.812	0.4	39.624	0.17	10.668	0.46	12.192	0.45
AN29	13.716	0.33	32.004	0.14	12.192	0.31	6.096	0.37
AN30	16.764	0.21	28.956	0.14	12.192	0.22	10.668	0.23
MEAN	21.6408	0.326	37.338	0.138	15.24	0.361	12.0396	0.382
ST. DEV.	4.712094	0.054259	4.269921	0.063056	3.048	0.112911	4.440571	0.074
GR. MEAN	31.5976	0.34	47.3456	0.215	24.9936	0.397	17.8816	0.461667
ST. DEV.	10.56542	0.110091	10.13915	0.112331	9.603216	0.11872	8.101923	0.121794

Table 4. Dimensions of natural and artificially constructed redds, Poverty Flat spawning area, South Fork Salmon River, September 11, 1990.

REDD	NATURAL REDD DIMENSIONS (m)					REDD	ARTIFICIAL REDD DIMENSIONS (m)				
	PIT		TAILSPILL		TOTAL		PIT		TAILSPILL		TOTAL
	Length	Width	Length	Width	Length		Length	Width	Length	Width	Length
REACH 1						REACH 1					
PR1	1.43	1.17	1.53	1.51	2.96	A1	1.08	1.44	2.2	1.63	3.28
PR2	1.51	1.57	1.74	1.8	3.25	A2	1	1.16	2.23	1.33	3.23
PR3	1.46	1.64	1.78	1.57	3.24	A3	0.75	1.01	1.7	1.35	2.45
PR4	2.1	2.48	3.23	1.99	5.33	A4	1.03	1.5	2.06	1.27	3.09
PR5	0.95	1.57	2.18	1.3	3.13	A5	0.85	1.08	2.11	1.32	2.96
PR6	1.63	1.7	2.51	2.09	4.14	A6	0.81	0.97	2	1.34	2.81
PR7	1.44	1.23	2.62	1.63	4.06	A7	0.9	1.07	1.58	1.28	2.48
PR8	1.31	2.1	2.41	1.93	3.72	A8	1.32	1.4	2.51	1.16	3.83
PR9	1.91	1.85	3.06	1.7	4.97	A9	1.23	1.44	1.95	1.44	3.18
PR10	1.51	1.41	1.99	1.42	3.5	A10	0.94	1.13	1.78	1.33	2.72
MEAN	1.525	1.672	2.305	1.694	3.83	MEAN	0.991	1.22	2.012	1.345	3.003
ST. DEV.	0.297935	0.375015	0.537424	0.243934	0.758353	ST.DEV.	0.172189	0.191833	0.261641	0.116383	0.393651
REACH 2						REACH 2					
PR11	1.22	1.19	2.03	1.36	3.25	AN11	1.01	1.14	2.07	1.1	3.08
PR12	1.44	1.52	2.36	1.95	3.8	AN12	0.96	1.18	2.02	1.56	2.98
PR13	1.28	1.24	1.15	1.46	2.43	AN13	1.27	1.24	3.02	1.46	4.29
PR14	1.24	1.12	2.27	1.7	3.51	AN14	1.11	1.14	1.68	1.3	2.79
PR15	1.28	1.11	1.67	1.36	2.95	AN15	1.17	1.3	2.15	1.29	3.32
PR16	1.46	1.46	1.94	1.68	3.4	AN16	0.98	1.13	2.26	1.3	3.24
PR17	1.11	1.02	1.9	1.14	3.01	AN17	0.86	1	1.85	1.25	2.71
PR18	1.84	0.96	2.35	1.18	4.19	AN18	0.99	0.96	1.84	1.12	2.83
PR19	1.2	1.42	1.57	1.64	2.77	AN19	1.58	1.12	1.44	1.29	3.02
PR20	1.41	1.15	2.8	1.5	4.21	AN20	1.08	1.35	2	1.11	3.08
MEAN	1.348	1.219	2.004	1.497	3.352	MEAN	1.101	1.156	2.033	1.278	3.134
ST.DEV.	0.195643	0.179858	0.446726	0.238162	0.560728	ST.DEV.	0.194034	0.11456	0.398624	0.141266	0.426056
REACH 3						REACH 3					
PR21	0.88	1.33	1.24	1.55	2.12	AN21	1.08	1.06	2.01	1.3	3.09
PR22	0.72	1.27	1.04	1.19	1.76	AN22	0.92	1.3	1.76	1.32	2.68
PR23	1.02	1.06	1.05	1.2	2.07	AN23	0.73	0.83	1.34	1.03	2.07
PR24	1.05	1.35	1.17	1.55	2.22	AN24	0.77	1.16	1.78	1.16	2.55
PR25	1.08	1.53	1.36	1.73	2.44	AN25	0.88	1.22	1.72	1.24	2.6
PR26	1.01	1.01	1.6	1.05	2.61	AN26	1.01	0.88	1.64	1.11	2.65
PR27	1.53	1.12	1.81	1.37	3.34	AN27	0.68	1.2	2.26	1.18	2.94
PR28	1.25	0.99	1.74	1.1	2.99	AN28	0.81	0.99	1.88	1.01	2.69
PR29	0.95	1.11	2.08	1.2	3.03	AN29	0.93	1.23	2.15	1.45	3.08
PR30	1.04	1.23	1.66	1.23	2.7	AN30	0.79	1.05	1.75	1.07	2.54
MEAN	1.053	1.2	1.475	1.317	2.528	MEAN	0.86	1.092	1.829	1.187	2.689
ST.DEV.	0.205331	0.163829	0.336103	0.212464	0.472203	ST.DEV.	0.12025	0.148916	0.249858	0.13372	0.284761
GR. MEAN	1.308667	1.363667	1.928	1.502667	3.236667	GR. MEAN	0.984	1.156	1.958	1.27	2.942
ST.DEV.	0.307091	0.33794	0.564053	0.278375	0.812413	ST.DEV.	0.192243	0.163597	0.324021	0.146014	0.4172

tailspill length. In Reach 3 artificial redds were significantly smaller except in pit width and tailspill length.

Dissolved Oxygen

The percent saturation of dissolved oxygen (DOSAT) and temperature are given for all the samples by sampling date in Tables 5 to 12. Debris and ice flows pulled the dissolved oxygen sampling probes from three of the 53 redds, all three were natural redds. These tables also include the percent saturation dissolved oxygen and temperature data for Blackmare Creek and the SFSR above Blackmare Creek approximately 1 km upstream from the spawning reaches, three water column samples within the spawning reach and three substrate samples in the spawning reach but not associated with redds.

The DOSAT for the three water column samples averaged nearly 90% for the sampling dates of Sept. 11, Oct 23, and Dec. 6. The maximum average dissolved oxygen content of the water column measured on Feb. 13 exceeded 100% saturation (about 12 mg/l). By the March sample, average DOSAT in the water column had declined to about 80% (9 mg/l). In both the April samples, the average DOSAT exceeded 90% saturation. On the last sampling date, May 13, DOSAT had declined to 82% saturation in Reaches 1 and 3, but remained over 100% in Reach 2. During the incubation period the DOSAT of the water column samples exceed that of the substrate samples by 10% saturation or more (2 mg/l). On two dates, Dec. 6 and April 25, there was about 5-6 mg/l less dissolved oxygen in the substrate samples. Dissolved oxygen levels in the artificial redds without eggs were generally inbetween levels measured in the water column and substrate (Figure 3).

Figure 3 illustrates the dissolved oxygen percent saturation for the eight sample dates for the water column and substrate and the average dissolved oxygen percent saturation for the artificial redds without eggs. Percent saturations are displayed by reach, since there were differences between the three spawning reaches, surprizingly even for the water column samples. For the first two sampling dates in the fall, Sept. 11 and Oct. 23, the average percent saturation of dissolved oxygen for the artificial redds at Reach 2 was significantly less than the averages at the other two reaches. On March 4, the average DOSAT at Reach 3 was significantly less than DOSAT at the other reaches. Differences in the DOSAT of the artificial redds between reaches over time are similar to the trends in the DOSAT of the water column. For example, the DOSAT of both the water column and artificial redds at Reach 2 are the lowest for the first three sampling dates and the highest for mid-winter and late spring sampling dates.

We hypothesize that differential contributions of ground water throughout the year may be causing differences in DOSAT between reaches. Regardless of the cause, these large differences between reaches have some monitoring implications. If artificial redds are used to monitor dissolved oxygen, they must be spatially located to include a wide range of conditions to account for any natural variability due to reach differences. Dissolved oxygen concentrations of the water column should be measured at each spawning reach (cluster of redds) to aid in interpreting the dissolved oxygen measurements from the redds.

Differences between redd types

The natural redds, artificial redds with eggs, and the artificial redds without eggs (10 each) at the downstream reach (Reach 1) were used to evaluate differences in dissolved oxygen and temperature between types of redds. Figure 4 illustrates the dissolved oxygen and temperature for the three redd types for each of the eight sampling dates. Temperature differences were pronounced between sampling dates, dropping from an average of about 12 ^{o}C at the beginning of the incubation period to less than 1 ^{o}C on December 6 and then gradually increasing to just over 5 ^{o}C immediately following fry emergence. At each sampling date, there were no significant differences in temperature between the types of redds.

For each sampling date, there were no significant differences in dissolved

Table 5. Percent saturation of dissolved oxygen and water temperature in natural and artificial chinook salmon redds and the water column at the Poverty Flats site, South Fork Salmon River, on September 11, 1990.

NATURAL REDD			ART. REDD WITH EGGS			ART. REDD WITHOUT EGGS		
Redd Id	Water Temp. C	Oxygen %	Redd Id	Water Temp. C	Oxygen %	Redd Id	Water Temp. C	Oxygen %
PR1	10.7	72.5	A1	11.0	74.7	AN1	11.1	77.6
PR2	11.2	79.8	A2	11.2	80.9	AN2	11.0	85.1
PR3	10.7	81.1	A3	10.8	82.8	AN3	11.1	78.7
PR4	11.3	77.6	A4	11.1	78.6	AN4	11.3	80.1
PR5	11.3	84.5	A5	11.1	80.6	AN5	11.0	87.0
PR6	11.8	76.2	A6[1]	13.2	90.4	AN6	11.7	86.3
PR7	11.7	90.1	A7	11.9	78.3	AN7	11.4	83.0
PR8	12.3	86.5	A8	11.9	78.3	AN8	12.0	82.8
PR9	12.8	97.3	A9	12.6	81.5	AN9	12.9	82.1
PR10	12.8	86.6	A10	12.9	80.8	AN10	13.0	63.5
MEAN	11.76	83.22		11.61[2]	79.61		11.65	80.62
SDEV.	.6931	7.3134		.7524	2.4075		.7561	6.7644
						AN11	14.4	69.8
						AN12	13.9	73.4
						AN13	15.5	74.3
						AN14	14.1	81.1
						AN15	15.1	68.6
						AN16	14.0	79.2
						AN17	14.7	71.6
						AN18	14.6	73.8
						AN19	15.3	85.5
						AN20	14.3	90.6
						MEAN	14.59	76.79
						SDEV.	.5567	7.1528
						AN21	14.9	87.0
						AN22	15.5	94.7
						AN23	15.0	86.5
						AN24	15.0	93.4
						AN25	15.5	74.8
						AN26	15.2	82.4
						AN27	15.0	85.4
						AN28	16.2	88.2
						AN29	16.1	96.4
						AN30	16.2	83.6
						MEAN	15.46	87.24
						SDEV.	0.5296	6.4450
ALL ARTIFICIAL REDDS (WITHOUT EGGS)						MEAN	13.90	81.55
						SDEV.	1.7634	7.8896

[1] New probe installed, D.O. collected about 1 hr after installation

[2] A6 not included

WATER COLUMN SAMPLES		
AT PR8	12.5	95.6
AT PR18	16.1	81.8
AT PR27	16.5	93.5
SFSR ABOVE BLACKMARE CREEK	16.8	103.4
BLACKMARE CREEK	12.1	101.4
BLACKMARE CREEK	11.6	96.3

Table 6. Percent saturation of dissolved oxygen and water temperature in natural and artificial chinook salmon redds and the water column at the Poverty Flats site, South Fork Salmon River, on October 23, 1990.

NATURAL REDD			ART. REDD WITH EGGS			ART. REDD WITHOUT EGGS		
Redd Id	Water Temp. C	Oxygen %	Redd Id	Water Temp. C	Oxygen %	Redd Id	Water Temp. C	Oxygen %
PR1	2.8	65.1	A1	3.1	69.7	AN1	3.2	88.2
PR2	2.8	80.4	A2	2.8	80.9	AN2	3.0	78.5
PR3	2.7	82.2	A3	2.8	78.1	AN3	3.0	86.8
PR4	3.0	77.1	A4	2.8	84.9	AN4	3.2	83.6
PR5	2.8	88.8	A5	2.6	89.4	AN5	2.6	89.2
PR6	2.8	80.6	A6	2.7	77.3	AN6	2.6	83.4
PR7	2.8	83.2	A7	2.8	73.7	AN7	2.7	83.3
PR8	2.7	87.1	A8	3.0	85.8	AN8	3.0	84.6
PR9	2.9	86.7	A9	3.0	92.2	AN9	2.7	77.9
PR10	3.2	84.0	A10	3.1	71.6	AN10	3.6	70.6
MEAN	2.85	81.52		2.87	80.36		2.96	82.61
SDEV.	0.1509	6.7631		0.1703	7.6129		0.3204	5.5935
						AN11	3.9	69.6
						AN12	3.7	84.4
						AN13	3.7	76.4
						AN14	4.2	65.7
						AN15	3.7	72.2
						AN16	3.9	72.3
						AN17	4.0	71.2
						AN18	4.1	63.5
						AN19	4.0	78.9
						AN20	3.7	88.1
						MEAN	3.89	74.23
						SDEV.	0.1853	7.8080
						AN21	4.6	81.7
						AN22	4.3	84.0
						AN23	4.2	70.3
						AN24	4.2	86.8
						AN25	4.6	93.5
						AN26	4.4	94.5
						AN27	4.4	84.5
						AN28	4.7	78.9
						AN29	4.6	72.8
						AN30	4.7	78.0
						MEAN	4.47	82.50
						SDEV.	0.1947	7.9339

SUBTRATE SAMPLES

Id	Temp. C	Oxygen %
SUB1	3.0	79.2
SUB2	4.0	63.7
SUB3	4.8	86.7
MEAN	3.9	76.5
SDEV.	0.9018	11.7296

ALL ARTIFICIAL REDDS (WITHOUT EGGS)

	Temp. C	Oxygen %
MEAN	3.77	79.78
SDEV.	0.6741	8.0062

WATER COLUMN SAMPLES

LOCATION	Temp. C	Oxygen %
AT PR8	2.9	92.7
AT PR18	4.1	77.2
AT PR27	4.8	102.3
SFSR ABOVE BLACKMARE CREEK	4.6	103.0
BLACKMARE CREEK	3.1	89.3

Table 7. Percent saturation of dissolved oxygen and water temperature in natural and artificial chinook salmon redds and the water column at the Poverty Flats site, South Fork Salmon River, on December 6, 1990.

NATURAL REDD			ART. REDD WITH EGGS			ART. REDD WITHOUT EGGS		
Redd Id	Water Temp. C	Oxygen %	Redd Id	Water Temp. C	Oxygen %	Redd Id	Water Temp. C	Oxygen %
PR1	0.5	86.2	A1	0.6	80.4	AN1	0.7	84.9
PR2			A2	0.6	82.3	AN2	0.5	54.4
PR3	0.3	83.3	A3	0.5	75.1	AN3	0.5	85.2
PR4	0.6	44.7	A4	0.7	67.9	AN4	0.7	89.8
PR5			A5	0.2	80.3	AN5	0.1	85.5
PR6			A6	0.3	73.3	AN6	0.2	84.2
PR7	0.2	88.6	A7	0.2	63.2	AN7	0.1	79.8
PR8	0.2	93.0	A8	0.2	86.0	AN8	0.1	90.8
PR9	0.1	89.6	A9	0.1	82.4	AN9	0.0	88.2
PR10	0.2	90.0	A10	0.4	79.8	AN10	0.3	89.5
MEAN	0.30	82.20		0.38	77.07		0.32	83.23
SDEV.	0.1826	16.8160		0.2098	7.1417		0.2616	10.6468

Redd Id	Water Temp. C	Oxygen %
AN11	0.8	85.7
AN12		
AN13	0.5	84.9
AN14		
AN15	0.7	75.3
AN16	0.8	77.0
AN17	0.7	82.8
AN18	0.6	70.1
AN19	0.6	81.0
AN20	0.3	84.0
MEAN	0.625	80.1
SDEV.	0.1669	5.4819
AN21	0.2	90.0
AN22		
AN23	0.6	83.9
AN24	0.6	70.3
AN25		
AN26	0.5	71.1
AN27	0.6	80.2
AN28		
AN29	0.4	87.5
AN30	0.5	96.4
MEAN	0.4857	82.77
SDEV.	.1464	9.6609

SUBSTRATE SAMPLES

Id	Temp. C	Oxygen %
SUB1	0.4	64.9
SUB2	0.6	68.0
SUB3	0.3	73.3
MEAN	0.43	68.73
SDEV.	0.1528	4.2477

ALL ARTIFICIAL REDDS (WITHOUT EGGS)

	Temp.	Oxygen
MEAN	0.46	82.10
SDEV.	0.2378	8.7523

WATER COLUMN SAMPLES

LOCATION	Temp. C	Oxygen %
AT PR8	0.1	93.9
AT PR18	0.3	87.7
AT PR27	0.3	96.1
SFSR ABOVE BLACKMARE CREEK	0.2	85.1
BLACKMARE CREEK	0.0	95.9

Table 8. Percent saturation of dissolved oxygen and water temperature in natural and artificial chinook salmon redds and the water column at the Poverty Flats site, South Fork Salmon River, on February 13, 1991.

NATURAL REDD			ART. REDD WITH EGGS			ART. REDD WITHOUT EGGS		
Redd Id	Water Temp. C	Oxygen %	Redd Id	Water Temp. C	Oxygen %	Redd Id	Water Temp. C	Oxygen %
PR1	1.4	101.7	A1	1.1	99.9	AN1	1.2	53.1
PR2			A2	1.1	101.7	AN2	1.1	89.6
PR3	1.3	101.5	A3	1.2	86.0	AN3	1.1	85.8
PR4	1.3	97.8	A4	1.3	100.6	AN4	1.4	106.5
PR5			A5	1.6	92.3	AN5	1.5	95.1
PR6	1.2	99.3	A6	1.1	100.0	AN6	1.2	95.8
PR7	1.1	98.1	A7	1.2	90.1	AN7	0.9	96.8
PR8	gone		A8	1.1	104.7	AN8	1.3	82.6
PR9	1.2	94.0	A9	1.1	77.0	AN9	1.0	99.7
PR10	1.2	99.3	A10	1.2	86.8	AN10	1.0	91.4
MEAN	1.24	98.81		1.20	93.91		1.17	89.64
SDEV.	0.0976	2.6054		0.1563	8.8883		0.1889	14.5566

SUBSTRATE SAMPLES

Id	Temp. C	Oxygen %
SUB1	1.2	96.5
SUB2		
SUB3		
MEAN		
SDEV.		

Redd Id	Water Temp. C	Oxygen %
AN11	1.2	100.4
AN12		
AN13	1.3	102.1
AN14	probe	gone
AN15		
AN16	1.1	102.5
AN17	1.1	92.4
AN18		
AN19		
AN20	1.5	107.4
MEAN	1.24	100.96
SDEV.	0.1673	5.4482
AN21		
AN22		
AN23		
AN24		
AN25		
AN26		
AN27		
AN28		
AN29		
AN30		
MEAN		
SDEV.		

ALL ARTIFICIAL REDDS (WITHOUT EGGS)

	Temp. C	Oxygen %
MEAN	1.19	93.41
SDEV.	0.1792	13.2367

WATER COLUMN SAMPLES

LOCATION	Temp. C	Oxygen %
AT PR8	1.1	105.2
AT PR18	1.2	108.3
AT PR27	0.5	106.3
SFSR ABOVE BLACKMARE CREEK	1.2	106.6
BLACKMARE CREEK	1.3	106.4

Table 9. Percent saturation of dissolved oxygen and water temperature in natural and artificial chinook salmon redds and the water column at the Poverty Flats site, South Fork Salmon River, on March 4, 1991.

NATURAL REDD			ART. REDD WITH EGGS			ART. REDD WITHOUT EGGS		
Redd Id	Water Temp. C	Oxygen %	Redd Id	Water Temp. C	Oxygen %	Redd Id	Water Temp. C	Oxygen %
PR1	1.6	92.6	A1	1.6	92.4	AN1	1.8	87.5
PR2			A2	1.6	95.8	AN2	1.7	83.8
PR3	1.7	78.9	A3	1.7	85.9	AN3	1.7	81.1
PR4	1.6	67.8	A4	1.6	89.6	AN4	1.6	85.3
PR5			A5	1.7	78.2	AN5	1.6	85.5
PR6	1.7	75.8	A6	1.7	73.4	AN6	1.7	84.7
PR7	1.7	86.4	A7	1.7	59.7	AN7	1.7	86.4
PR8	probe gone		A8	1.7	71.6	AN8	1.7	70.6
PR9	1.7	79.2	A9	1.7	63.3	AN9	1.7	64.2
PR10	1.7	58.3	A10	1.7	64.0	AN10	1.7	66.6
MEAN	1.67	77.0		1.67	77.39		1.69	79.57
SDEV.	0.0408	11.372		0.0483	13.0239		0.0568	8.8757

Redd Id	Water Temp. C	Oxygen %
AN11	1.9	86.2
AN12		
AN13	1.8	80.9
AN14		
AN15	1.7	80.6
AN16	1.7	78.1
AN17	1.8	77.6
AN18	1.8	81.6
AN19	1.8	85.6
AN20	1.7	91.4
MEAN	1.775	82.75
SDEV.	.0707	4.6654
AN21	2.0	70.5
AN22		
AN23	1.8	56.8
AN24	1.8	73.5
AN25		
AN26	1.8	69.8
AN27	1.8	58.2
AN28		
AN29	1.8	77.7
AN30		
MEAN	1.833	67.75
SDEV.	.0816	8.4254
ALL ARTIFICIAL REDDS (WITHOUT EGGS) MEAN	1.75	77.68
ALL ARTIFICIAL REDDS (WITHOUT EGGS) SDEV.	0.0884	9.4392

SUBSTRATE SAMPLES

Id	Temp. C	Oxygen %
SUB1	1.6	78.8
SUB2	1.8	61.2
SUB3	2.0	59.3
MEAN	1.8	66.43
SDEV.	0.2000	10.7519

WATER COLUMN SAMPLES

LOCATION	Temp. C	Oxygen %
AT PR8	1.7	73.7
AT PR18	1.7	94.4
AT PR27	1.7	71.1
SFSR ABOVE BLACKMARE CREEK	1.7	82.8
BLACKMARE CREEK	1.1	92.9

Table 10. Percent saturation of dissolved oxygen and water temperature in natural and artificial chinook salmon redds and the water column at the Poverty Flats site, South Fork Salmon River, on April 8, 1991.

NATURAL REDD			ART. REDD WITH EGGS			ART. REDD WITHOUT EGGS		
Redd Id	Water Temp. C	Oxygen %	Redd Id	Water Temp. C	Oxygen %	Redd Id	Water Temp. C	Oxygen %
PR1	2.1	81.5	A1	2.3	87.3	AN1	2.4	74.5
PR2			A2	2.0	90.0	AN2	2.2	75.0
PR3	2.2	86.2	A3	2.0	93.2	AN3	2.2	87.5
PR4	2.3	70.4	A4	2.1	90.6	AN4	2.2	95.3
PR5			A5	2.1	81.4	AN5	2.1	92.5
PR6	2.3	69.2	A6	2.3	83.3	AN6	2.3	80.6
PR7	2.1	91.7	A7	2.5	67.7	AN7	2.1	90.0
PR8	probe gone		A8	2.1	83.2	AN8	2.2	70.7
PR9	2.3	68.4	A9	2.2	66.3	AN9	2.3	86.3
PR10	2.3	61.4	A10	2.3	60.3	AN10	2.5	69.0
MEAN	2.23	75.54		2.19	80.33		2.25	82.14
SDEV.	0.0951	11.0139		0.1595	11.4938		0.1269	9.4492
						AN11	2.7	77.7
						AN12		
						AN13		
						AN14		
						AN15	2.9	86.1
						AN16		
						AN17	2.7	61.2
						AN18	2.8	73.1
						AN19	2.7	95.8
						AN20	2.7	95.6
						MEAN	2.75	81.58
						SDEV.	0.0837	13.5758
						AN21	2.8	91.0
						AN22		
						AN23		
						AN24		
						AN25		
						AN26		
						AN27	2.7	86.2
						AN28		
						AN29	2.8	89.7
						AN30	2.8	96.4
						MEAN	2.78	90.83
						SDEV.	0.0500	4.2335
ALL ARTIFICIAL REDDS (WITHOUT EGGS)						MEAN	2.51	83.71
						SDEV.	0.2800	10.3444

SUBSTRATE SAMPLES

Id	Temp. C	Oxygen %
SUB1	2.3	79.4
SUB2	2.8	70.3
SUB3	2.8	81.4
MEAN	2.63	77.03
SDEV.	0.2887	5.9164

WATER COLUMN SAMPLES

LOCATION	Temp. C	Oxygen %
AT PR8	2.2	96.1
AT PR18	3.2	88.4
AT PR27	3.0	93.7
SFSR ABOVE BLACKMARE CREEK	3.0	100.5
BLACKMARE CREEK	1.8	97.3

Table 11. Percent saturation of dissolved oxygen and water temperature in natural and artificial chinook salmon redds and the water column at the Poverty Flats site, South Fork Salmon River, on April 25, 1991.

NATURAL REDD			ART. REDD WITH EGGS			ART. REDD WITHOUT EGGS		
Redd Id	Water Temp. C	Oxygen %	Redd Id	Water Temp. C	Oxygen %	Redd Id	Water Temp. C	Oxygen %
PR1	3.5	91.4	A1	3.7	86.7	AN1	3.7	94.3
PR2			A2	3.6	104.1	AN2	3.5	86.6
PR3	3.5	84.5	A3	3.4	93.8	AN3	3.7	89.9
PR4	3.6	64.5	A4	3.6	94.7	AN4	3.5	95.6
PR5			A5	3.5	88.9	AN5	3.6	98.1
PR6	3.6	76.5	A6	3.5	79.6	AN6	3.9	89.2
PR7	3.3	83.0	A7	3.8	53.2	AN7	3.4	94.8
PR8	probe	gone	A8	3.5	96.7	AN8	3.6	77.8
PR9	3.8	80.0	A9	3.6	58.2	AN9	3.7	62.9
PR10	3.7	73.3	A10	4.0	70.8	AN10	4.0	82.1
MEAN	3.57	79.03		3.62	82.67		3.66	87.13
SDEV.	0.1604	8.8802		0.1751	16.9880		0.1838	10.6147
						AN11	3.8	83.3
SUB1	3.7	63.4				AN12		
SUB2	3.8	83.3				AN13		
SUB3	4.0	67.0				AN14		
MEAN						AN15		
SDEV.						AN16		
						AN17		
						AN18		
						AN19	3.7	101.7
						AN20	3.6	99.0
						MEAN	3.70	94.67
						SDEV.	0.1000	9.9360
						AN21		
						AN22		
						AN23		
						AN24		
						AN25		
						AN26		
						AN27		
						AN28		
						AN29	3.5	91.0
						AN30	3.5	88.0
						MEAN	3.5	89.5
						SDEV.	0.0	2.1213
ALL ARTIFICIAL REDDS (WITHOUT EGGS)								
						MEAN	3.65	88.95
						SDEV.	0.1642	9.8115

WATER COLUMN SAMPLES

LOCATION	Temp. C	Oxygen %
AT PR8	3.6	95.7
AT PR18	3.7	107.1
AT PR27	3.8	88.7
SFSR ABOVE BLACKMARE CREEK	3.7	87.0
BLACKMARE CREEK	3.0	91.3

Table 12. Percent saturation of dissolved oxygen and water temperature in natural and artificial chinook salmon redds and the water column at the Poverty Flats site, South Fork Salmon River, on May 13, 1991.

NATURAL REDD			ART. REDD WITH EGGS			ART REDD WITHOUT EGGS		
Redd Id	Water Temp. C	Oxygen %	Redd Id	Water Temp. C	Oxygen %	Redd Id	Water Temp. C	Oxygen %
PR1	5.3	76.5	A1	5.3	61.0	AN1	5.4	83.6
PR2			A2	5.5	80.7	AN2	5.3	85.1
PR3	5.2	83.0	A3	5.2	90.3	AN3	5.3	87.7
PR4	5.5	53.0	A4	5.2	91.9	AN4	5.3	88.2
PR5			A5	5.4	67.4	AN5	5.3	92.8
PR6	5.5	75.3	A6	5.5	78.8	AN6	5.4	78.6
PR7	5.2	84.5	A7	5.1	72.3	AN7	5.1	85.2
PR8	probe	gone	A8	5.3	78.0	AN8	5.3	68.9
PR9	5.5	66.6	A9	5.6	67.4	AN9	5.4	49.3
PR10	5.5	56.0	A10	5.3	51.8	AN10	5.2	68.2
MEAN	5.39	70.70		5.34	73.96		5.30	78.76
SDEV.	0.1464	12.5348		0.1577	125692		0.0943	13.1145

SUBSTRATE SAMPLES

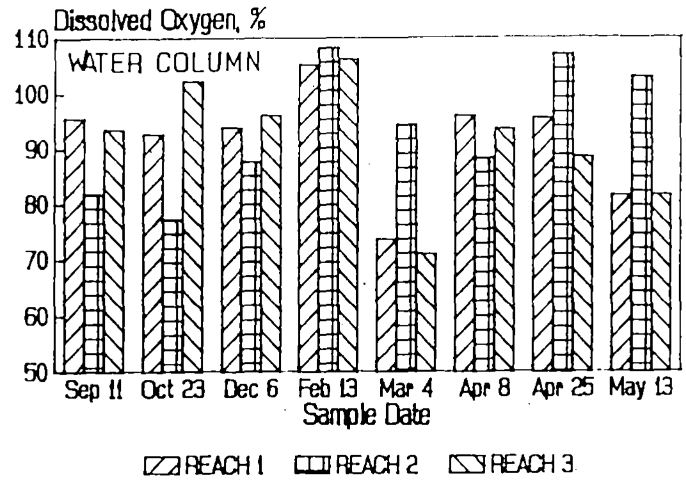
Id	Temp. C	Oxygen %
SUB1	5.2	80.3
SUB2	5.7	80.7
SUB3	5.5	77.9
MEAN	5.47	79.63
SDEV.	0.2517	1.5144

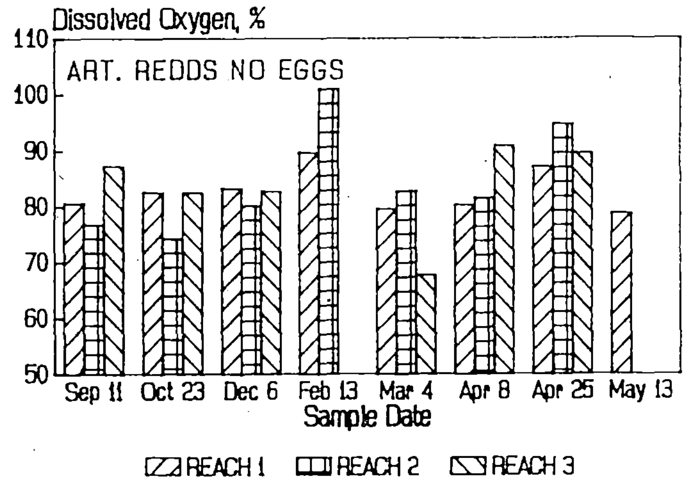
WATER COLUMN SAMPLES AT UPSTREAM EDGE OF DEPRESSION

Id	Temp. C	Oxygen %
PR4	5.4	97.9
PR9	5.6	93.5
PR10	5.5	90.4
MEAN	5.50	93.93
SDEV.	0.1000	3.7687

WATER COLUMN SAMPLES

LOCATION	Temp. C	Oxygen %
AT PR8	5.5	81.6
AT PR18	5.6	103.0
AT PR27	5.5	81.7
SFSR ABOVE BLACKMARE CREEK	5.8	93.1
BLACKMARE CREEK	5.2	97.1





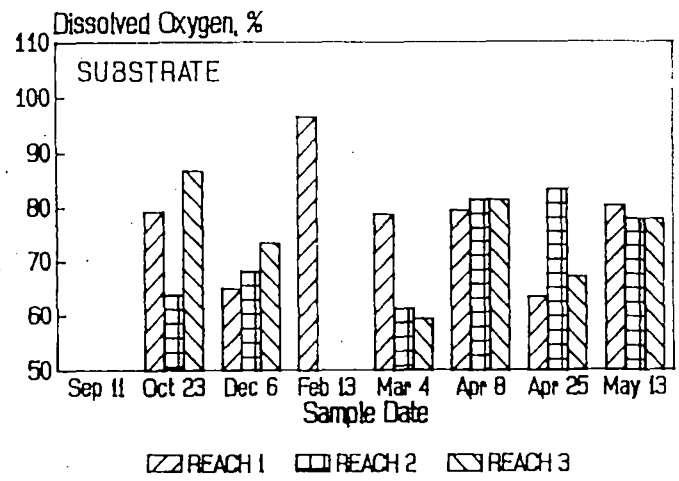


Figure 3. Percent saturation of dissolved oxygen for the water column, artificial redds without eggs, and substrate by stream reach and sample date.

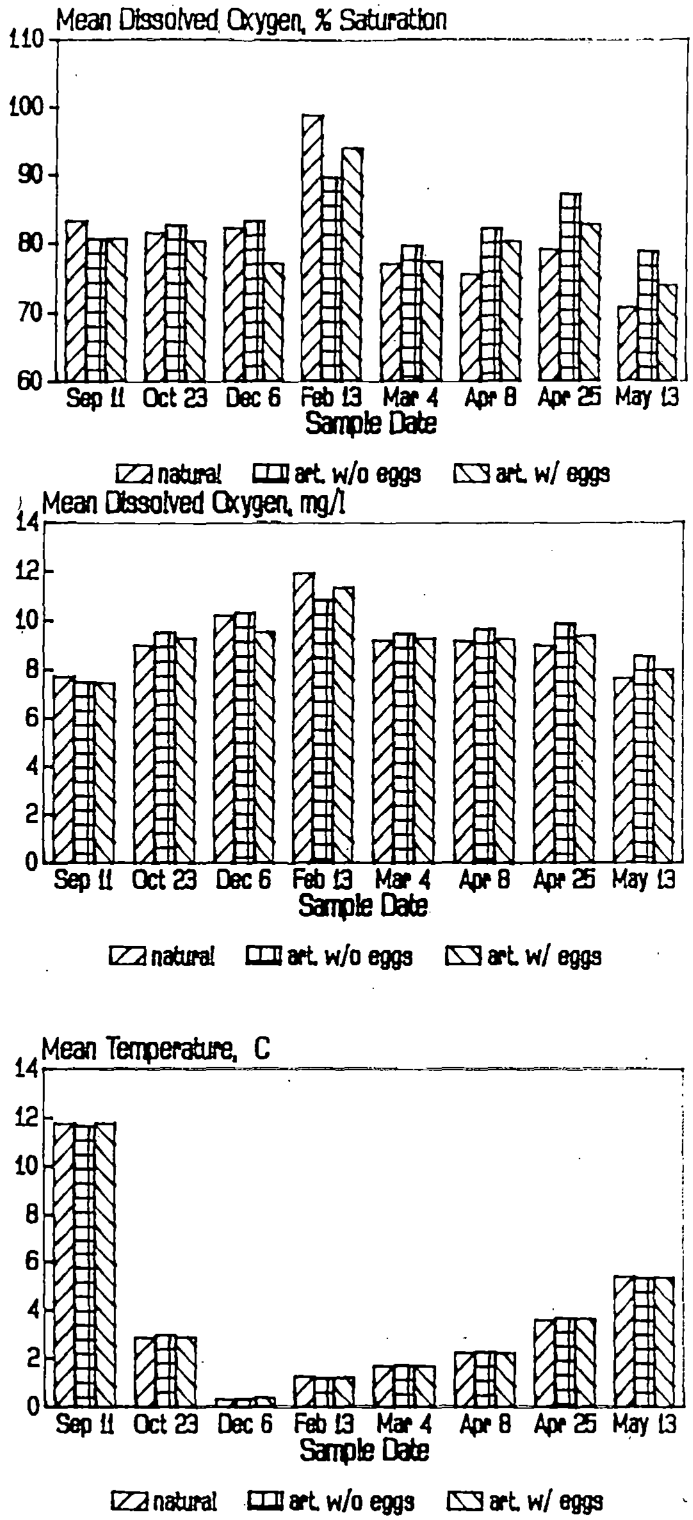


Figure 4. Mean dissolved oxygen concentration, percent saturation and temperature by redd type and sample date.

oxygen, expressed either as percent saturation or mg/l, between redd types. However, there are some important trends that may have physical or biological importance. For those sampling dates beginning March 4 and extending to the post emergence sample date, the natural chinook salmon redds had the lowest average dissolved oxygen on each date. During the same time period, the artificial redds with eggs had lower dissolved oxygen than the artificial redds without eggs. On April 25, the sampling date just prior to emergence, the average concentrations for the natural, artificial with eggs, and artificial without eggs redds are respectively, 8.95, 9.36, and 9.84 mg/l (79.0%, 82.7%, and 87.1%). Since the natural redds were not freeze cored until after fry emergence, we cannot know which of the dissolved oxygen sampling probes were located within egg pockets. We would expect less dissolved oxygen within the egg pocket environment due to respiration by the eggs/fry or the BOD caused by decay of any dead eggs/fry and metabolic wastes. Similar trends in dissolved oxygen were observed in steelhead trout redds in 1990 (King and Thurow 1990). Steelhead redds averaged less dissolved oxygen than the artificial redds near the end of the incubation period. Steelhead redds also exhibited less dissolved oxygen within egg pocket samples as compared to redd samples outside of the egg pocket.

Results of the chinook salmon and steelhead redd studies suggest that in order to accurately monitor dissolved oxygen in redds, probes must be placed within the egg pocket environment. The probe used in the studies reported here was placed adjacent to the egg baskets in the artificial redds. The probe was too far from the egg environment to be able to accurately detect the dissolved oxygen concentration within the egg baskets near the implanted eggs. The probe needs to be redesigned to fit within the egg baskets of the artificial redds. A redesigned smaller probe is now in use in 1991 research on the redd environment of Yellowstone cutthroat trout. For comparison purposes, we installed larger probes adjacent to the egg baskets and smaller (new) probes within the egg baskets. Preliminary results, based on one sampling date for 19 artificial redds, showed some interesting results. Dissolved oxygen as measured with the smaller probe (within the egg basket) averaged 7.75 mg/l compared to 7.38 mg/l measured with the larger probe (outside the egg basket). Sampling dissolved oxygen within the egg pocket alleviates the criticism that there may be differences in dissolved oxygen within and exterior to the egg basket.

Particle Size Distribution

We present results for the percent of fines <6.35 mm in our sampling sites because this has been accepted as a useful index of gravel quality in Batholith streams. Appendices A-I contain the percent fines <0.85 mm, and calculated Geometric Means and Fredle indices.

Surrounding substrate

If we assume the undisturbed sites surrounding redds are representative of chinook salmon spawning substrate, they can be used to reflect the initial condition of gravel before it is altered by fish. As previously described, physical characteristics of the three study reaches varied and we also observed differences in substrate particle sizes between the reaches. Within surrounding sites we observed significantly fewer fines in Reach 1 as compared to reaches 2 and 3. Reach 1 exhibited significantly fewer fines in the <6.35 mm size fraction in the 0-10 cm, 20-30 cm, and 0-30 cm strata (Table 13). Percent fines in the 10-20 cm strata were similar across all three reaches. Reaches 2 and 3 had similar concentrations of fines across all strata.

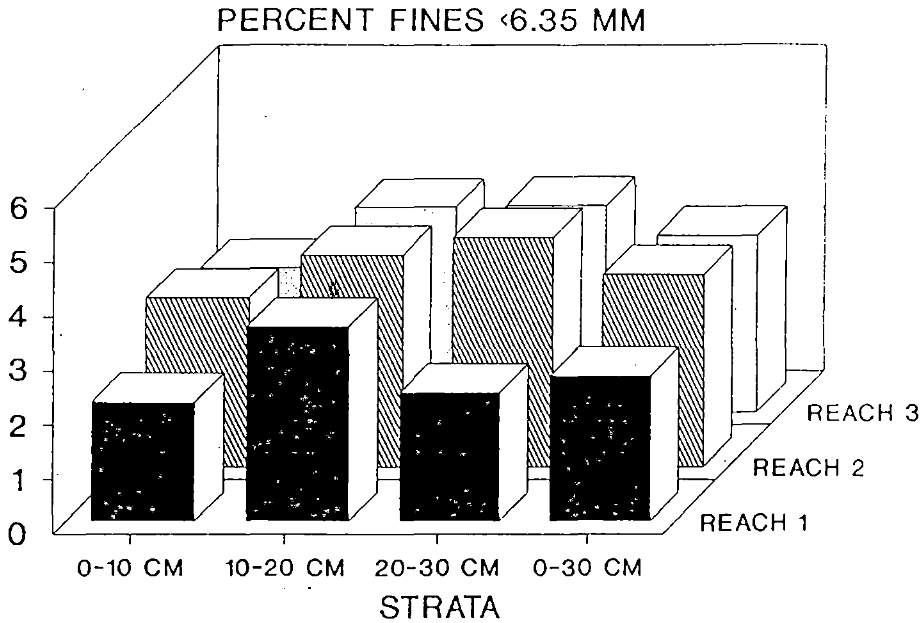
Within individual reaches, we also observed differences in percent fines between strata (Table 13). The upper strata (0-10 cm) exhibited the lowest concentration of fines less than 6.35 mm in all three reaches (Figure 5). Within Reach 1, the 10-20 cm strata contained significantly larger concentrations of fines than the other strata. Reaches 2 and 3 were very similar and there were no significant differences in the concentrations of fines between strata.

Pooling of similar data for reaches 2 and 3 revealed differences in percent fines by sampling date and strata (Table 14). Within the 0-10 cm strata, percent fines

Table 13. Mean percent substrate passing a 6.35 mm sieve, by reach and site (dates pooled) Poverty Flat, 1990-1991.

REACH	STRATA	SURROUNDING	N	ARTIFICIAL W/O EGGS	N	INTRUSION	N	NATURAL REDD	N	ARTIFICIAL W/EGGS	N
1	0-10	0.219	10	0.258	10			0.265	10	0.219	9
1	10-20	0.358	9	0.361	10			0.314	10	0.284	9
1	20-30	0.236	8	0.343	9			0.380	8	0.292	8
1	pooled	0.267	10	0.317	10	0.150	10	0.294	10	0.264	10
2	0-10	0.312	10	0.314	10						
2	10-20	0.390	10	0.319	10						
2	20-30	0.422	10	0.279	10						
2	pooled	0.354	10	0.313	10	0.139	10				
3	0-10	0.267	10	0.328	10						
3	10-20	0.378	10	0.262	10						
3	20-30	0.381	10	0.297	10						
3	pooled	0.326	10	0.302	10	0.077	10				

PERCENT FINES BY REACH AND STRATA
SURROUNDING SITES



PERCENT FINES BY DATE AND STRATA
SURROUNDING SITES

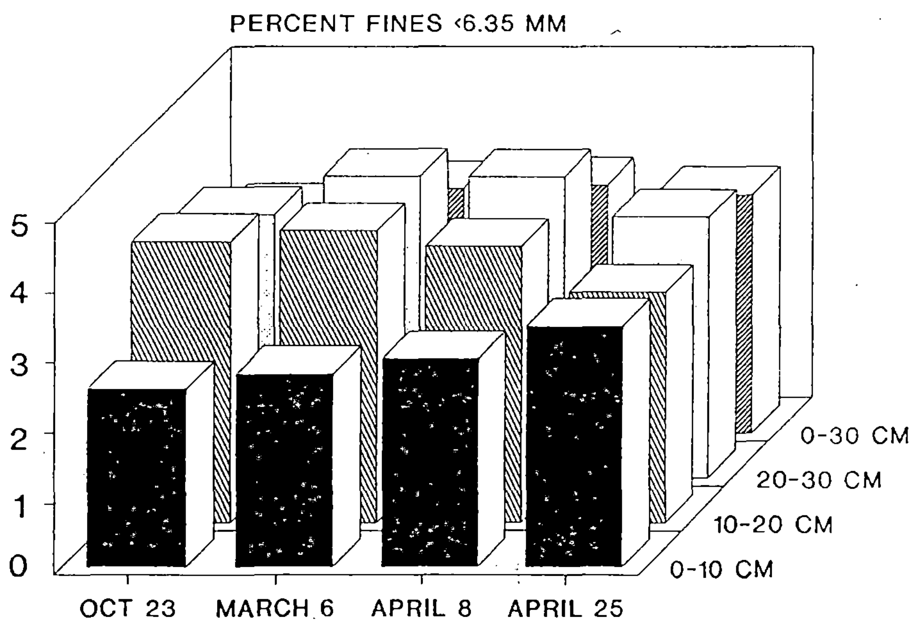


Figure 5. Top graph: Percent fines less than 6.35mm by Reach and Strata (dates pooled) in surrounding sites.
Bottom graph: Percent fines less than 6.35mm by date and strata (reaches 2 and 3 pooled) in surrounding sites.

Table 14. Mean percent substrate passing a 6.35 mm sieve, by date and site (reaches pooled) Poverty Flat, 1990-1991.

DATE	STRATA	SURROUNDING	N	ARTIFICIAL W/O EGGS	N	INTRUSION	N
10-23-90	0-10	0.251	5	0.341	5		
10-23-90	10-20	0.400	5	0.256	5		
10-23-90	20-30	0.375	5	0.252	5		
10-23-90	pooled	0.317	5	0.321	5	0.058	5
3-6-91	0-10	0.272	5	0.243	5		
3-6-91	10-20	0.415	5	0.293	5		
3-6-91	20-30	0.429	5	0.333	5		
3-6-91	pooled	0.349	5	0.286	5	0.169	5
4-8-91	0-10	0.294	5	0.329	5		
4-8-91	10-20	0.393	5	0.334	5		
4-8-91	20-30	0.428	5	0.294	5		
4-8-91	pooled	0.354	5	0.315	5	0.096	5
4-25-91	0-10	0.341	5	0.370	5		
4-25-91	10-20	0.327	5	0.279	5		
4-25-91	20-30	0.372	5	0.275	5		
4-25-91	pooled	0.341	5	0.309	5	0.107	5
5-14-91	0-10	0.219	10	0.258	10		
5-14-91	10-20	0.358	9	0.361	10		
5-14-91	20-30	0.256	8	0.343	9		
5-14-91	pooled	0.267	10	0.317	10	0.150	10

increased over time and fines were significantly more abundant on April 25 as compared to October 23 (Figure 5). Within the other three strata, there were no significant differences by date. Differences in strata were reduced over time. The 0-10 cm strata had significantly fewer fines than the 10-20 cm and 20-30 cm strata on October 23 and March 6. On April 8, only the 0-10 cm and 20-30 cm strata differed significantly, and on April 25, there were no differences between any strata.

Chinook salmon redds

Unfortunately, because of the low abundance of chinook salmon in the SFSR, we were unable to sample particle size distributions in natural redds until after fry emergence. As a result, we were not able to document the location of egg pockets in the redds. However, the data still allows us to describe conditions within the redd environment. The 20-30 cm strata contained significantly more fines than the upper strata (Table 15). Fines in the 0-10 and 10-20 cm strata were not significantly different.

A linear regression of the percent fines in surrounding sites vs the percent fines in chinook salmon redds suggests the initial gravel condition in subsurface layers influences the final concentration of fines in the redd (Figure 6). In the surface layer (0-10 cm strata) percent fines in the redd did not change as percent fines in the surrounding substrate increased. In the 10-20 and 20-30 cm strata, fines in the redd increased as fines in the surrounding substrate increased.

Natural redds did not contain fewer fines <6.35 mm than artificial redds or surrounding substrate sites. Within the 0-10 and 10-20 cm strata, all three sites had similar concentrations of fines (Table 13). In the 20-30 cm strata, the surrounding substrate sites had significantly fewer fines than the natural and artificial redds. Research on steelhead suggests that egg pockets contain significantly fewer fines than other sites within and outside the redd (King and Thurow 1990). As previously discussed, our inability to define egg pockets with certainty limits the analysis of particles size distributions within the redd.

Artificial redds

Artificial redds we constructed followed a dissimilar trend in percent fines < 6.35 mm as compared to surrounding sites. Artificial redds in Reach 1 contained significantly fewer fines in the 0-10 cm strata but significantly more fines in the 10-20 cm strata as compared to reaches 2 and 3 (Table 13, Figure 7). There were no statistically significant differences in fines between any of the reaches within the other two strata. Reaches 2 and 3 had similar concentrations of fines across all strata.

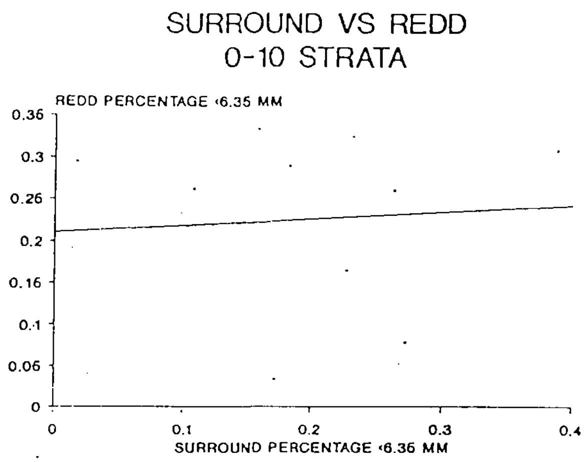
Within individual reaches, we observed differences in percent fines between strata. Unlike the surrounding sites, the upper strata did not always contain the fewest fines (Figure 7). Within Reach 1, the 0-10 cm strata contained significantly fewer fines than the 10-20 cm or 20-30 cm strata (Table 13). Artificial redds in reaches 2 and 3 contained similar concentrations of fines across all strata.

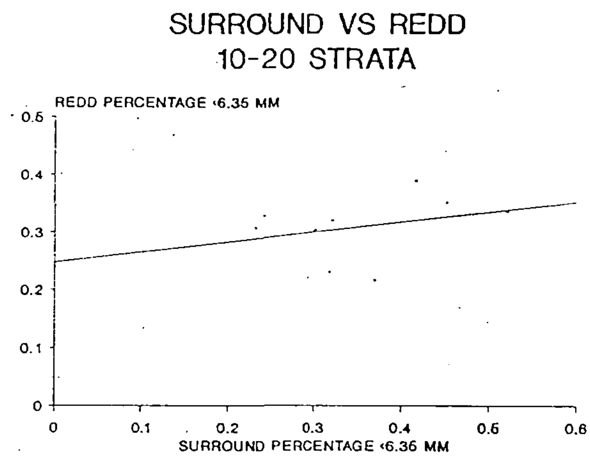
Pooling of similar data in reaches 2 and 3 also revealed differences in percent fines by sampling date and strata (Table 14). We did not observe any consistent trend in percent fines over time within the strata (Figure 7). Within the 0-10 cm strata, the March 6 sample contained significantly fewer fines than the April 8 sample. Within the other three strata, there were no significant differences by date. Differences in strata fluctuated by date. On October 23 and April 26, the 0-10 cm strata contained the largest concentration of fines while on March 6 the 0-10 cm strata contained the fewest fines.

Unlike the natural redds, the initial concentration of fines did not influence the final percent fines in the artificial redds. Within all strata of artificial redds, we did not observe any increase in percent fines as fines increased in the surrounding substrate (Figure 8).

Table 15. Mean percent substrate passing a 6.35 mm sieve, by date and Reach, Poverty Flat, 1990-1991.

DATE	REACH	STRATA	SURROUNDING	N	ARTIFICIAL W/O EGGS	N	INTRUSION	N
10-23-90	2	0-10	0.270	2	0.305	2		
10-23-90	2	10-20	0.482	2	0.307	2		
10-23-90	2	20-30	0.375	2	0.284	2		
10-23-90	2	pooled	0.337	2	0.349	2	0.111	2
10-23-90	3	0-10	0.238	3	0.365	3		
10-23-90	3	10-20	0.345	3	0.222	3		
10-23-90	3	20-30	0.375	3	0.230	3		
10-23-90	3	pooled	0.303	3	0.302	3	0.023	3
3-6-91	2	0-10	0.291	2	0.234	2		
3-6-91	2	10-20	0.356	2	0.298	2		
3-6-91	2	20-30	0.527	2	0.263	2		
3-6-91	2	pooled	0.362	2	0.265	2	0.205	2
3-6-91	3	0-10	0.259	3	0.249	3		
3-6-91	3	10-20	0.454	3	0.289	3		
3-6-91	3	20-30	0.364	3	0.379	3		
3-6-91	3	pooled	0.340	3	0.300	3	0.145	3
4-8-91	2	0-10	0.318	3	0.331	3		
4-8-91	2	10-20	0.401	3	0.354	3		
4-8-91	2	20-30	0.468	3	0.303	3		
4-8-91	2	pooled	0.370	3	0.324	3	0.112	3
4-8-91	3	0-10	0.258	2	0.325	2		
4-8-91	3	10-20	0.382	2	0.302	2		
4-8-91	3	20-30	0.369	2	0.280	2		
4-8-91	3	pooled	0.328	2	0.301	2	0.073	2
4-25-91	2	0-10	0.347	3	0.356	3		
4-25-91	2	10-20	0.341	3	0.307	3		
4-25-91	2	20-30	0.336	3	0.262	3		
4-25-91	2	pooled	0.344	3	0.311	3	0.140	3
4-25-91	3	0-10	0.333	2	0.392	2		
4-25-91	3	10-20	0.307	2	0.238	2		
4-25-91	3	20-30	0.426	2	0.293	2		
4-25-91	3	pooled	0.337	2	0.307	2	0.058	2
5-14-91	1	0-10	0.219	10	0.258	10		
5-14-91	1	10-20	0.358	9	0.361	10		
5-14-91	1	20-30	0.236	8	0.343	9		
5-14-91	1	pooled	0.267	10	0.317	10	0.150	10





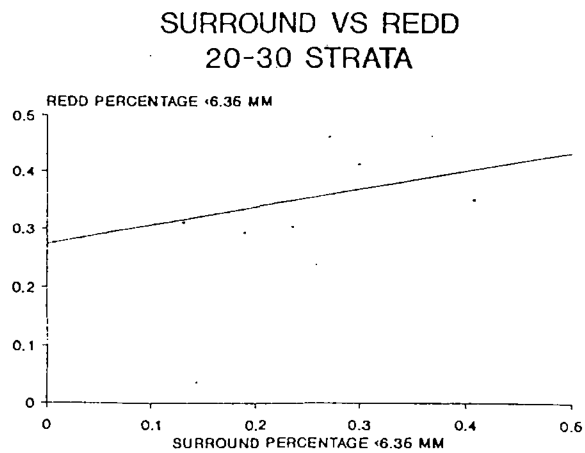
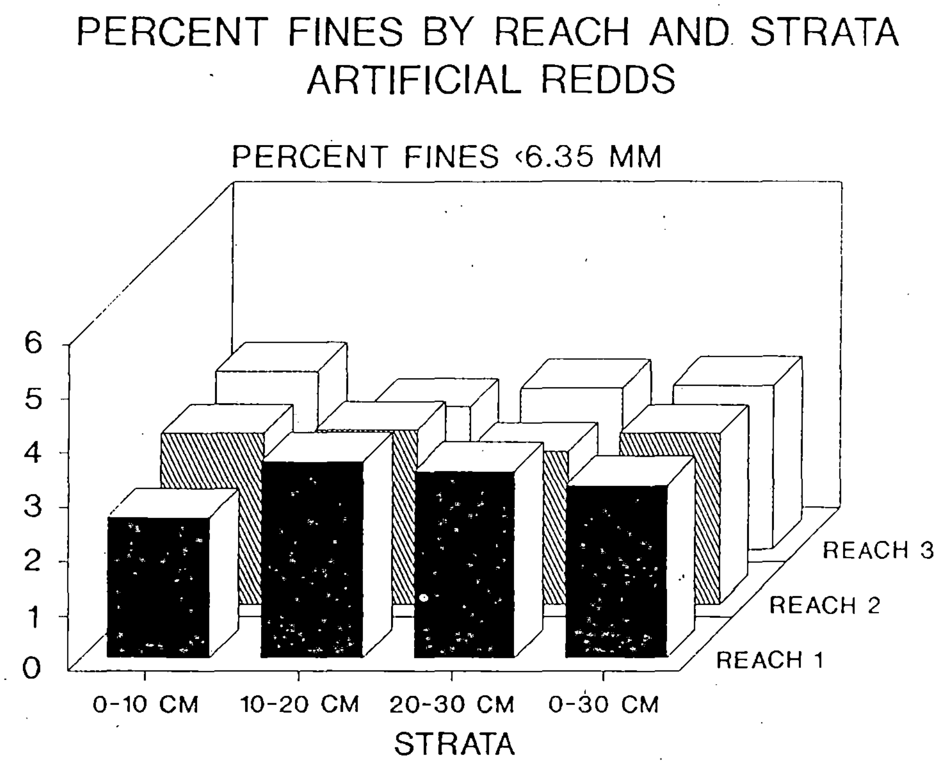


Figure 6. Plot of the percentage fines less than 6.35mm in natural redds versus surrounding sites, by strata.



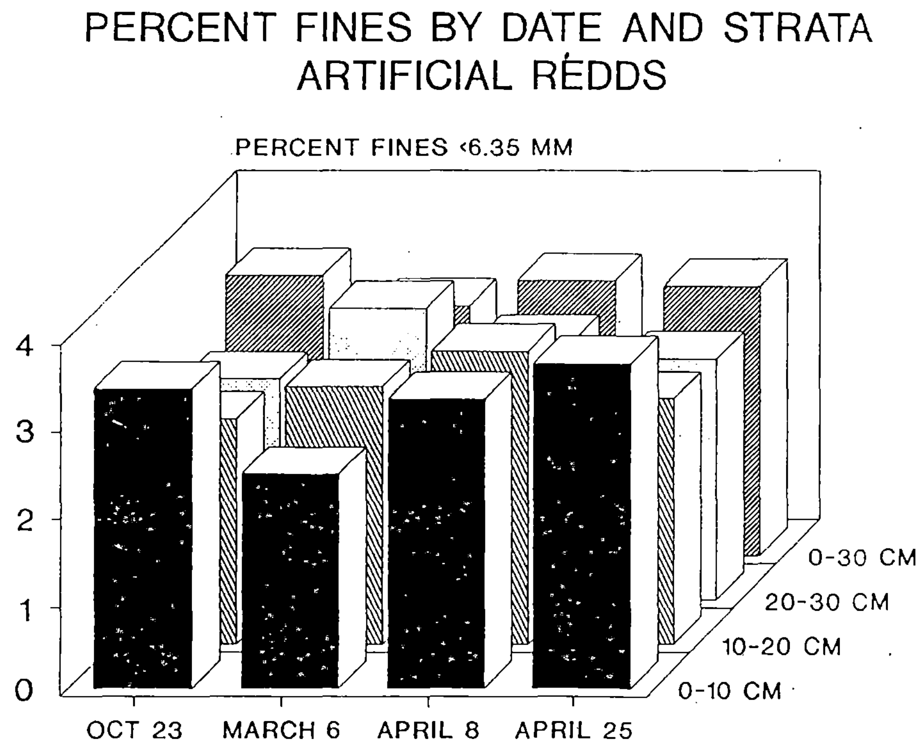


Figure 7. Top graph: Percent fines less than 6.35mm by Reach and Strata (dates pooled) in artificual redds.
Bottom graph: Percent fines less than 6.35mm by date and strata (reaches 2 and 3 pooled) in artificial redds.

As a result of the low availability of chinook salmon eggs, we installed only ten artificial redds with eggs and 30 without eggs. If we describe the relationship between paired sites with and without eggs, artificial redds without eggs may be used as surrogates for artificial redds with eggs. There were no significant differences in percent fines <6.35 mm between artificial redds with and without eggs across any strata (Table 15).

Artificial redds differed from surrounding sites depending on the reach, strata, and date. Within Reach 1, at the 20-30 cm strata, surrounding sites had significantly fewer fines than artificial redds. Within reaches 2 and 3, artificial redds had significantly fewer fines than surrounding sites in the 10-20 cm strata on October 23 and March 6. The percent fines were similar between the sites in April. In the 20-30 cm strata, artificial redds had significantly fewer fines than surrounding sites.

Intrusion sites
Within the intrusion sites, substrate cleaned to remove fines less than 6.35 mm rapidly accumulated fines. Reach 2 accumulated more fines than Reach 3, but differences in fines < 6.35 mm were not significant between the reaches (Table 15). The data suggests that fines were moving through the reach, even during relatively low flow periods in September and October. Fines apparently were deposited on intrusion sites where free interstitial areas existed. Pooling of data from the two reaches illustrated that percent fines (< 6.35 and < 0.85 mm) increased significantly from October 23 to March 6 and thereafter fines decreased, although not significantly (Figure 9). The decrease may have been a result of scouring of surface fines by increased flows after March 6.

Intrusion sites in Reach 1 were all sampled on May 14 and they contained concentrations of fines that were similar to samples collected in Reaches 2 and 3 on April 25 (Table 14). Intrusion sites apparently collected fines of different sizes at different rates. Within Reach 1, intrusion sites contained significantly fewer fines <6.35 mm than the 0-30 cm strata in the natural redds, artificial redds, or surrounding sites but significantly more fines <0.85 mm than artificial redds (Table 13). In reaches 2 and 3, intrusion sites also contained significantly fewer fines <6.35 mm than artificial redds and surrounding sites.

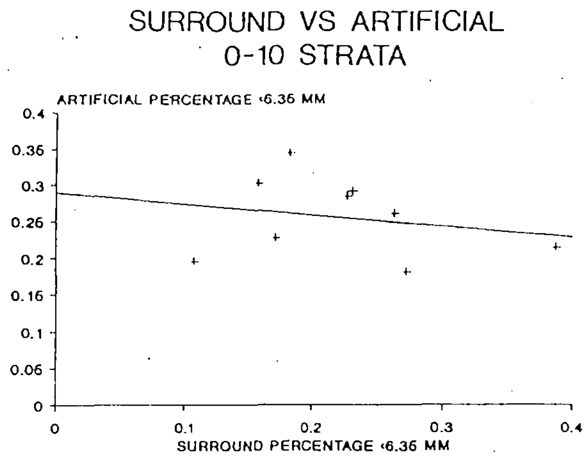
Relationships Between Percent Fines and Dissolved Oxygen

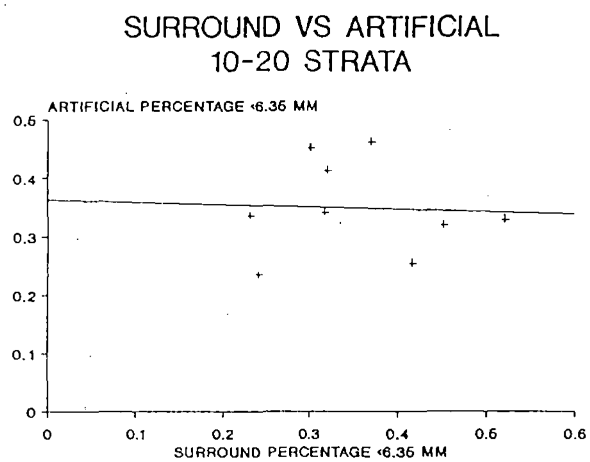
Relationships between dissolved oxygen and fine sediments were evaluated for each sampling date. This was necessary because of the large differences in stream temperature and stream discharge between sampling dates which may have a pronounced effect on oxygen content. Stratifying the data by sampling date reduced the sample size to five, except for the last sampling date, May 13, when sample sizes ranged from seven to ten.

Artificial Redds Without Eggs

Throughout the incubation period, September to May, the relationships between dissolved oxygen and fine sediments can only be examined for the artificial redds without eggs. Consequently, any apparent relationships may be different from redds with eggs (artificial or natural).

Correlation analysis was conducted for each sampling date on percent saturation (DOSAT) and concentration, mg/l, (DOMGL) of dissolved oxygen, along with the following sediment parameters: the fredle index (F), the geometric mean (G), the percentage finer than 6.35 mm diameter (P6.35) and the percentage finer than 0.85 mm diameter (P0.85), for each of the three depth strata and the pooled strata. On three sampling dates, Oct. 23, April 8, and May 13 there were no significant (P>R=0.1) correlations between dissolved oxygen and any of the sediment parameters. On the other two sampling dates there were several significant correlations and the "best" correlations are shown below.





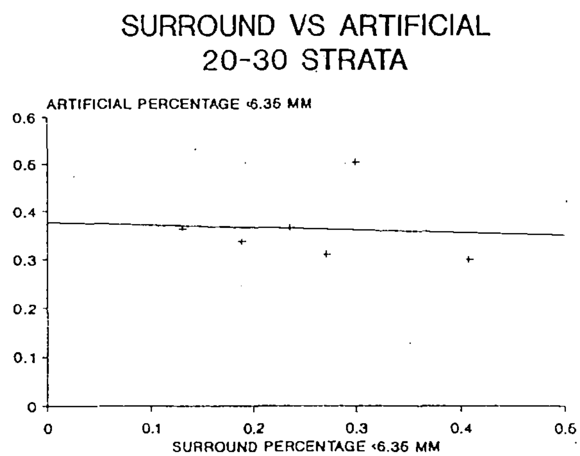


Figure 8. Plot of the percentage fines less than 6.35mm in artificial redds versus surrounding sites, by strata.

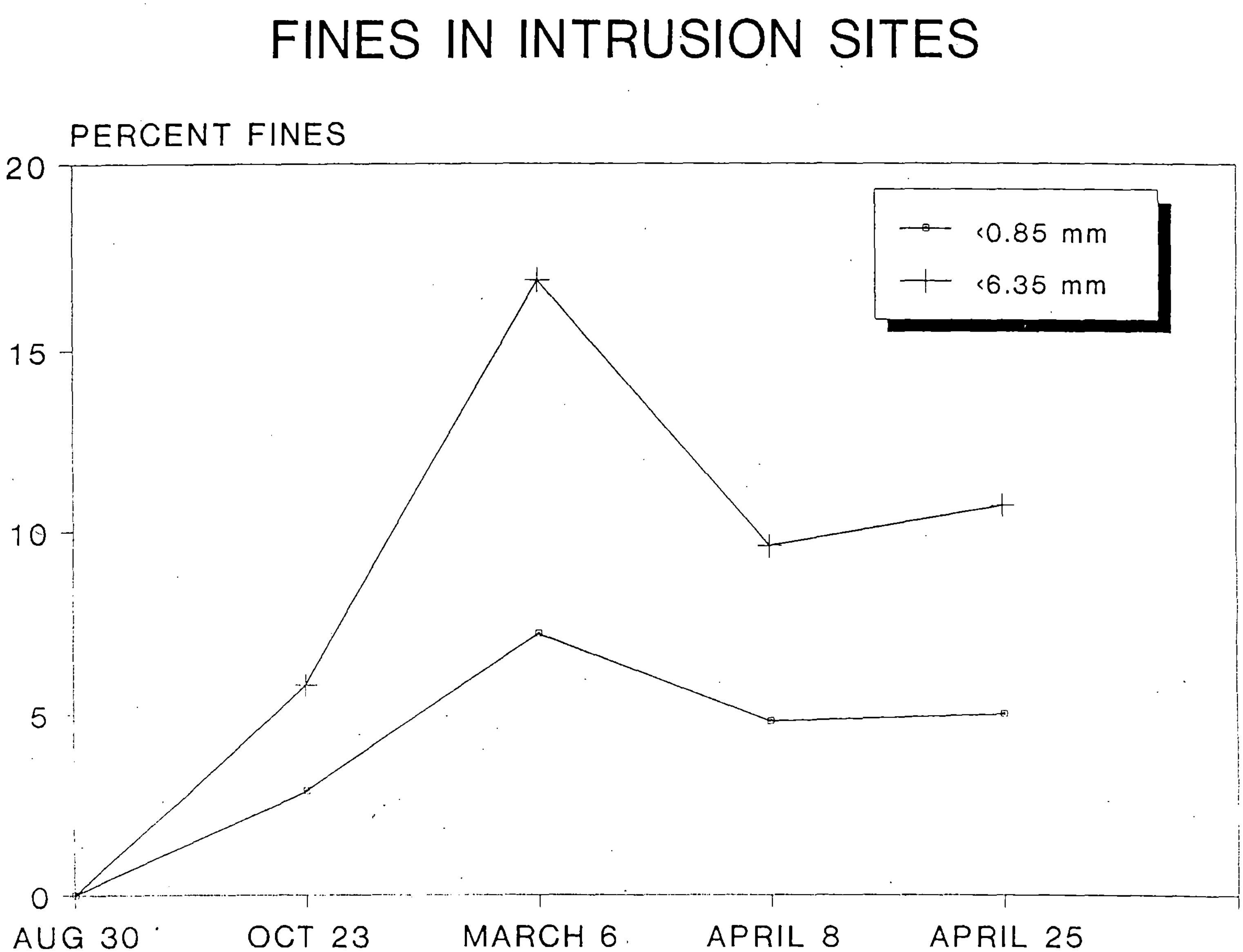


Figure 9. Percent fines less than 6.35mm and 0.85mm in intrusion sites, by date (reaches 2 and 3 pooled).

Sampling Date	Best Correlation	R	P>R
March 4	DOSAT vs P6.35 (20-30 cm strata)	-0.88	0.052
	DOMGL vs P6.35 (20-30 cm strata)	-0.87	0.054
April 26	DOSAT vs P6.35 (20-30 cm strata)	-0.88	0.048
	DOMGL vs P6.35 (20-30 cm strata)	-0.89	0.042

Significant inverse correlations occurred between the percentage of sediment less than 6.35 mm in the deepest strata for both DOSAT and DOMGL. Figure 10 illustrates these data for all five sampling dates as well as trend lines through the data. There is a tendency at all dates for an inverse relationship between percent saturation of dissolved oxygen and fine sediment content (P6.35).

All Redd Types

On the sampling date just after predicted emergence, May 13, freeze coring and dissolved oxygen measurements were made in the natural redds, artificial redds with eggs, and artificial redds without eggs at Reach 1. Correlation analysis revealed a significant inverse relationship between DOSAT and P6.35 (10-20 cm strata) for the artificial redds with eggs (R=-0.57, P>R=0.08). Figure 11 illustrates this relationship and shows the individual data points for all three redd types. On this date there was considerable variation in the data and no significant difference (alpha=0.1) between average DOSAT for the different redd types. However, data for both of the redd types with eggs tend to cluster around the trend line, while the data for the artificial redds without eggs all fall above the trend line, indicating higher values of DOSAT for any given level of P6.35. This would be expected if there was less oxygen demand in the artificial redds without eggs, due to the absence of dead eggs, dead alevins, or metabolic wastes.

Sample Size Considerations

Dissolved oxygen

The variation in the dissolved oxygen data can be used to determine the number of redds needed to monitor dissolved oxygen for different levels of precision and confidence. The data from the last sampling date is used since it exhibited the lowest average DOSAT value and any monitoring should include that period of greatest stress due to reduced dissolved oxygen. Table 16 illustrates the sample size required for estimation the mean DOSAT within +/- 5% and +/- 10% at the 90% confidence interval. These were calculated using the following equation (Freeze, 1967):

$$n = \frac{t^2 s^2}{e^2}$$

where, n= sample size
t= Student's t (n-1)
s= standard deviation
e= precision

Table 16. Sample size of redds needed for dissolved oxygen sampling at two levels of precision at the 90% confidence level.

PRECISION	NATURAL CHINOOK REDDS	ARTIFICIAL REDDS W/ EGGS	ARTIFICIAL REDDS W/O EGGS
+/- 5% DOSAT	24	23	21
+/- 10% DOSAT	6	6	5

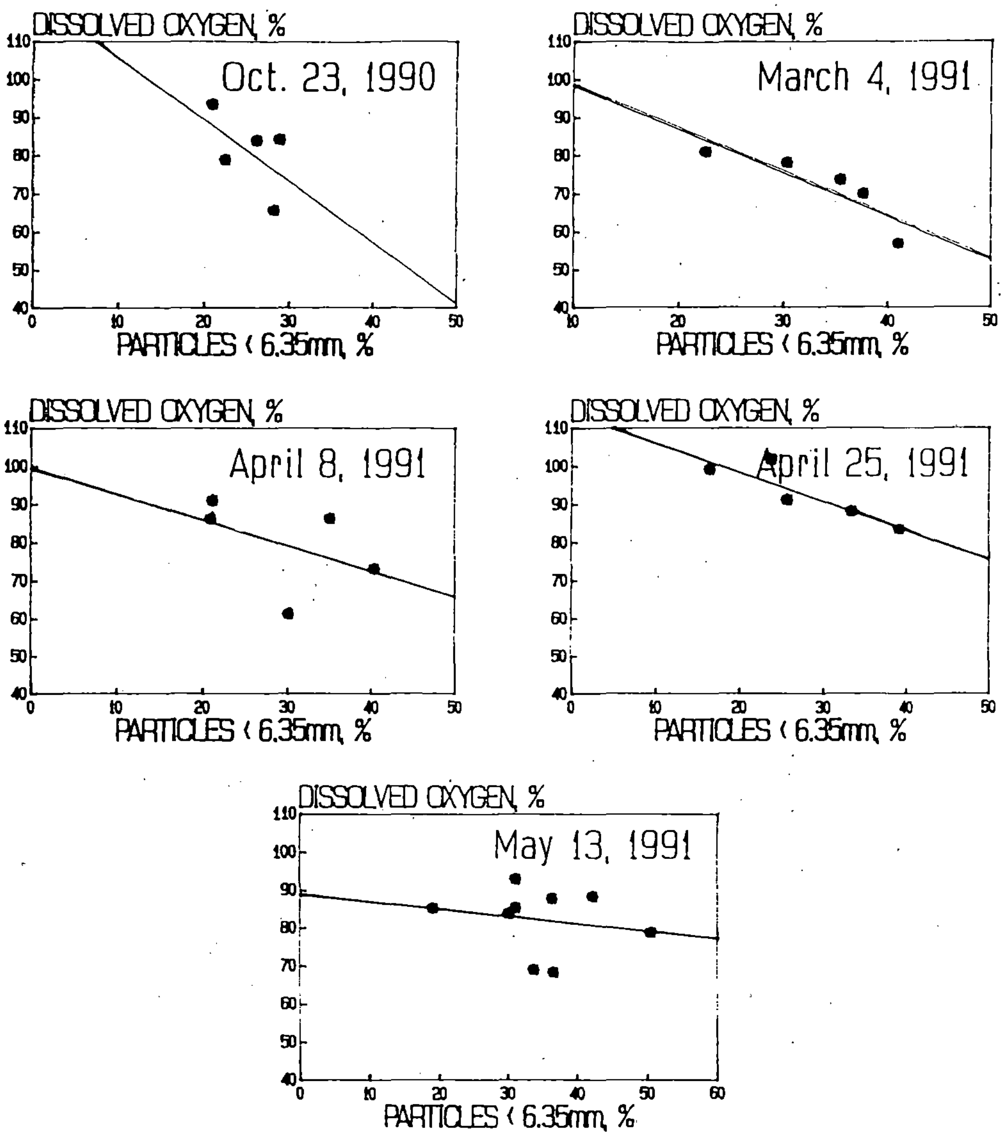


Figure 10. Relationship between percent fines (<6.35mm) and percent saturation of dissolved oxygen by sample date for artificial redds without eggs.

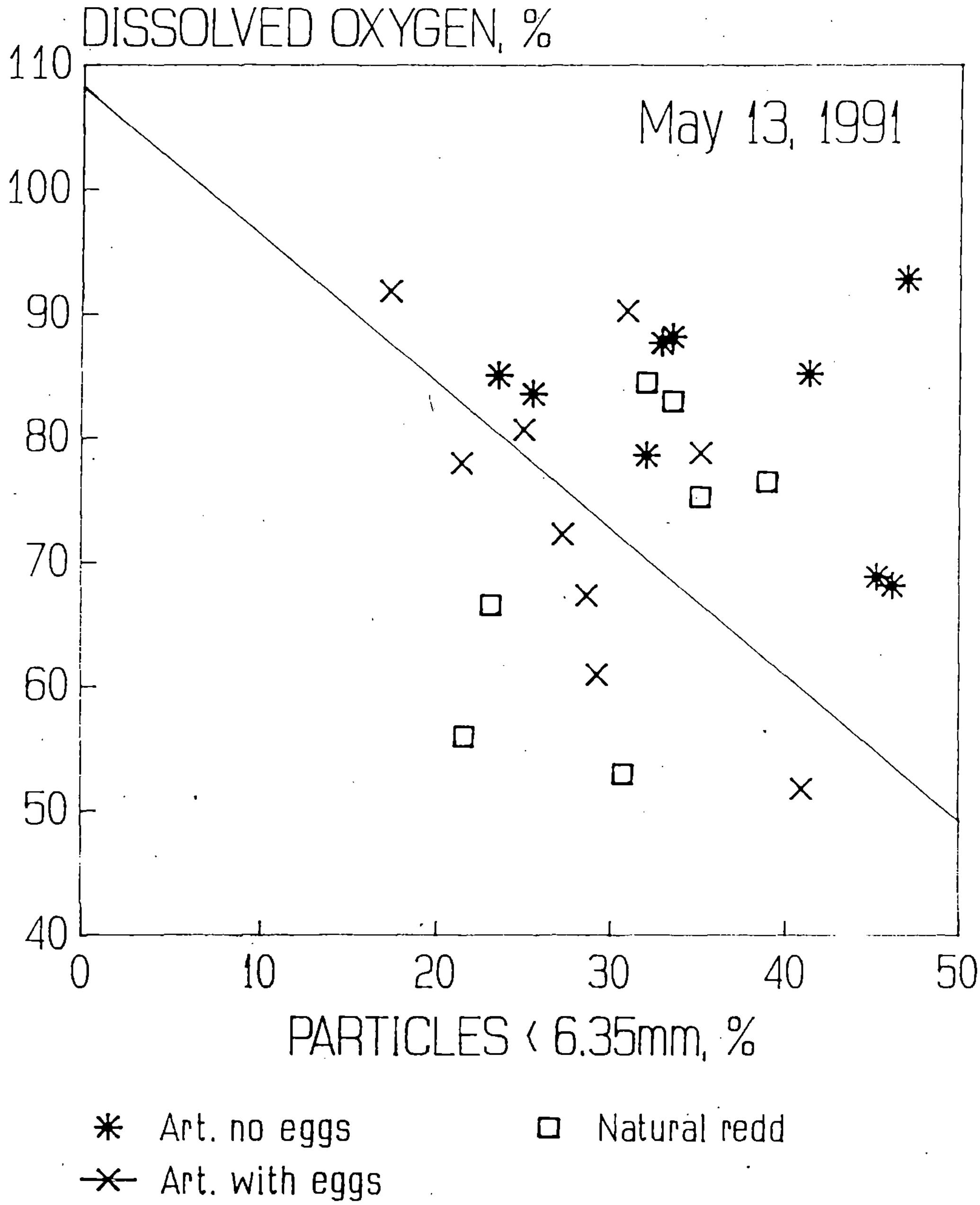


Figure 11. Relationship between percent fines (<6.35mm) and percent saturation of dissolved oxygen by redd type for the sampling date following predicted emergence.

Percent fines

We also used the variance associated with the percent fine sediment (<6.35 and <0.85 mm) samples to estimate sample size requirements for the 0-30 cm strata. We estimated the number of redds needed to be sampled to determine average percentages of fine sediments for different levels of precision at the 90% confidence level (Table 17). The precision levels for the <0.85mm samples were calculated to represent the same relative level of precision as compared to the <6.35mm samples which had a considerably larger mean. For example, +/- 5% for the % <6.35 mm and +/- 1.1% for the % <0.85 mm both represent the same precision around the respective means.

Table 17. Sample size of redds needed for percent fines sampling at two levels of precision at the 90% confidence level.

PARAMETER	PRECISION	NATURAL CHINOOK REDDS	ARTIFICIAL REDDS W/ EGGS	ARTIFICIAL REDDS W/O EGGS
%<6.35mm	+/- 2% FINES	30	19	69
	+/- 5% FINES	5	3	11
%<0.85mm	+/- 0.4% FINES	162	68	103
	+/- 1.1% FINES	21	9	14

The coefficient of variation associated with the percentage of fines less than 0.85mm was always greater than that for the percentage of fines less than 6.35mm; therefore, the sample sizes required for the <0.85mm parameter are considerable larger.

This method is appropriate for estimating sample sizes to determine means with a certain precision and confidence level. This method is not appropriate for estimating sample sizes required to detect differences between means either within the same site or between different sites such as artificial and natural redds.

SUMMARY

1. In August 1990, we began research to evaluate artificial redd monitoring as a technique to measure the effect of fine sediment on beneficial uses of streams by studying chinook salmon redds in the South Fork Salmon River. We selected four types of sampling sites: natural chinook salmon redds, artificially constructed redds, sites in undisturbed substrate surrounding redds, and sites with artificially cleaned substrate. We measured physical parameters including water depths and velocities, intergravel dissolved oxygen, intragravel velocity, and particle size distribution.

2. The research was conducted in three spawning reaches. We observed substantial variation in depths, velocities, dissolved oxygen concentrations, temperatures, and particle size distributions between the reaches. A variety of factors, including ground water inflow may have influenced differences between reaches.

3. Depths and velocities in natural chinook salmon redds were very similar across all reaches even though physical characteristics of the reaches and dimensions of the redds differed. This suggests that fish were able to construct redds with fairly specific depths and velocities. It also suggests that the fishes ability to create a redd with certain depth and velocity characteristics may be more important than redd dimensions. Differences in redd dimensions may be a result of physical conditions in the reach and differences in fish size.

4. Preliminary results suggest that our ability to mimic conditions in natural redds with artificial redds was variable. Artificial redds were generally deeper with slower velocities as compared to natural redds. Artificial redds also exhibited more variation in depths and velocities and less variation in dimensions than natural redds.

5. Dissolved oxygen saturation in the stream water column averaged 90% from September to December, increased to 100% in February, and fluctuated from 80 to 90% from March to May. Dissolved oxygen saturation in the water column exceeded levels measured in substrate outside of redds by 10% or more.

6. Because of the apparent variation in dissolved oxygen across spawning reaches, sites for monitoring dissolved oxygen in spawning gravels should be spatially located to include a range of conditions used by fish. Dissolved oxygen concentrations should also be measured in the water column at each spawning reach to aid in interpreting dissolved oxygen data from spawning gravels.

7. We did not observe any significant differences in dissolved oxygen concentrations or temperatures between natural redds and artificial redds with or without eggs. However, redds with eggs (both natural and artificial) exhibited declining dissolved oxygen concentrations as incubation progressed. Decreased dissolved oxygen concentrations may have been influenced by respiration and development of eggs and fry and the decay of dead eggs and metabolic wastes.

8. To accurately measure dissolved oxygen concentrations in natural and artificial redds, probes must be placed within the egg pocket and within the artificial egg baskets. A smaller, prototype probe is currently being tested.

9. The initial concentration of fines in spawning gravels (measured in undisturbed surrounding sites) influenced the final concentrations of fines in completed chinook salmon redds. In strata below 10 cm, fines increased in the redd as fines increased in the surrounding substrate.

10. Unlike our observations in steelhead redds in 1990, samples from natural chinook salmon redds did not contain significantly fewer fines than surrounding gravels. Our inability to sample redds until after emergence of fry limited our ability to define egg pockets with certainty.

11. The initial concentration of fines did not influence the final concentration of fines in artificial redds. However, artificial redds contained similar concentrations of fines as natural redds.

12. Substrate cleaned to remove fines less than 6.35 mm (intrusion sites) rapidly accumulated fines, even during low flow periods in September and October. Fines increased significantly from August to March, and decreased thereafter, possibly as a result of scouring of surface fines.

13. On two sampling dates, we observed a significant inverse correlation between the percent fines less than 6.35 mm in the deepest strata of artificial redds without eggs and dissolved oxygen concentrations. We did not observe a similar correlation in natural redds.

14. We calculated sample size requirements for determining means values of dissolved oxygen and percent fines for different levels of precision at the 90% confidence level. There was less variation in percent saturation of dissolved oxygen within redd type than in either percent fines <6.35 mm or <0.85 mm. Sample sizes of redds required to measure dissolved oxygen concentrations were always smaller than those required to measure levels of percent fines.

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APPENDICES

Appendix A Mean percent substrate passing a 0.85 mm sieve, by reach and site (dates pooled) Poverty Flat, 1990-1991.

REACH	STRATA	SURROUNDING	N	ARTIFICIAL W/O EGGS	N	INTRUSION	N	NATURAL REDD	N	ARTIFICIAL W/EGGS	N
1	0-10	0.073	10	0.058	10			0.069	10	0.055	9
1	10-20	0.108	9	0.075	10			0.086	10	0.070	9
1	20-30	0.072	8	0.060	9			0.126	8	0.052	8
1	pooled	0.084	10	0.063	10	0.090	10	0.084	10	0.063	10
2	0-10	0.104	10	0.059	10						
2	10-20	0.132	10	0.062	10						
2	20-30	0.147	10	0.046	10						
2	pooled	0.120	10	0.056	10	0.065	10				
3	0-10	0.091	10	0.063	10						
3	10-20	0.118	10	0.054	10						
3	20-30	0.119	10	0.064	10						
3	pooled	0.105	10	0.060	10	0.034	10				

Appendix C Mean Fredle indices of substrate by reach and site, Poverty Flat, 1990-1991.

REACH	STRATA	SURROUNDING	N	ARTIFICIAL W/O EGGS	N	INTRUSION	N	NATURAL REDD	N	ARTIFICIAL W/EGGS	N
1	0-10	8.236	10	5.654	10			7.610	10	7.456	9
1	10-20	3.199	9	3.568	10			4.015	10	4.907	9
1	20-30	7.208	8	4.139	9			2.795	8	5.476	8
1	pooled	5.652	10	4.200	10	8.082	10	4.641	10	5.401	10
2	0-10	3.834	10	4.690	10						
2	10-20	2.564	10	4.966	10						
2	20-30	2.350	10	6.130	10						
2	pooled	2.838	10	4.613	10	9.174	10				
3	0-10	5.310	10	4.111	10						
3	10-20	2.935	10	5.740	10						
3	20-30	2.418	10	5.600	10						
3	pooled	3.407	10	4.286	10	12.691	10				

Appendix B Mean geometric mean of substrate by reach and site (dates pooled) Poverty Flat, 1990-1991.

REACH	STRATA	SURROUNDING	N	ARTIFICIAL W/O EGGS	N	INTRUSION	N	NATURAL REDD	N	ARTIFICIAL W/EGGS	N
1	0-10	16.341	10	13.173	10			15.038	10	15.256	9
1	10-20	9.433	9	9.556	10			11.046	10	12.471	9
1	20-30	14.872	8	11.036	9			8.525	8	13.153	8
1	pooled	13.433	10	11.136	10	15.796	10	12.002	10	13.200	10
2	0-10	11.318	10	11.401	10						
2	10-20	8.617	10	11.762	10						
2	20-30	7.657	10	15.441	10						
2	pooled	9.546	10	12.134	10	16.995	10				
3	0-10	13.562	10	11.237	10						
3	10-20	9.145	10	15.175	10						
3	20-30	8.546	10	15.169	10						
3	pooled	10.698	10	13.049	10	22.299	10				

Appendix D Mean percent substrate passing a 0.85 mm sieve, by date and site (reaches pooled) Poverty Flat, 1990-1991.

DATE	STRATA	SURROUNDING	N	ARTIFICIAL W/O EGGS	N	INTRUSION	N
10-23-90	0-10	0.082	5	0.065	5		
10-23-90	10-20	0.125	5	0.044	5		
10-23-90	20-30	0.118	5	0.042	5		
10-23-90	pooled	0.101	5	0.052	5	0.029	5
3-6-91	0-10	0.089	5	0.039	5		
3-6-91	10-20	0.139	5	0.062	5		
3-6-91	20-30	0.146	5	0.066	5		
3-6-91	pooled	0.116	5	0.054	5	0.072	5
4-8-91	0-10	0.109	5	0.071	5		
4-8-91	10-20	0.143	5	0.075	5		
4-8-91	20-30	0.148	5	0.057	5		
4-8-91	pooled	0.128	5	0.067	5	0.048	5
4-25-91	0-10	0.110	5	0.070	5		
4-25-91	10-20	0.094	5	0.051	5		
4-25-91	20-30	0.119	5	0.055	5		
4-25-91	pooled	0.104	5	0.059	5	0.050	5
5-14-91	0-10	0.073	10	0.058	10		
5-14-91	10-20	0.108	9	0.075	10		
5-14-91	20-30	0.072	8	0.060	9		
5-14-91	pooled	0.084	10	0.063	10	0.090	10

Appendix E Mean geometric mean of substrate by date and site (reaches pooled) Poverty Flat, 1990-1991.

DATE	STRATA	SURROUNDING	N	ARTIFICIAL W/O EGGS	N	INTRUSION	N
10-23-90	0-10	14.917	5	11.354	5		
10-23-90	10-20	8.674	5	15.769	5		
10-23-90	20-30	8.754	5	16.577	5		
10-23-90	pooled	11.353	5	12.330	5	22.938	5
3-6-91	0-10	13.536	5	14.430	5		
3-6-91	10-20	7.622	5	12.872	5		
3-6-91	20-30	7.563	5	13.101	5		
3-6-91	pooled	9.843	5	13.486	5	17.771	5
4-8-91	0-10	11.541	5	10.894	5		
4-8-91	10-20	8.489	5	11.772	5		
4-8-91	20-30	6.795	5	14.937	5		
4-8-91	pooled	9.300	5	12.348	5	19.771	5
4-25-91	0-10	9.765	5	8.597	5		
4-25-91	10-20	10.739	5	13.461	5		
4-25-91	20-30	9.295	5	16.606	5		
4-25-91	pooled	9.994	5	12.200	5	18.107	5
5-14-91	0-10	16.341	10	13.173	10		
5-14-91	10-20	9.433	9	9.556	10		
5-14-91	20-30	14.872	8	11.036	9		
5-14-91	pooled	13.433	10	11.136	10	15.796	10

Appendix F Mean Fredle indices of substrate by date and site (reaches pooled) Poverty Flat, 1990-1991.

DATE	STRATA	SURROUNDING	N	ARTIFICIAL W/O EGGS	N	INTRUSION	N
10-23-90	0-10	6.138	5	3.812	5		
10-23-90	10-20	3.018	5	6.301	5		
10-23-90	20-30	2.649	5	6.818	5		
10-23-90	pooled	3.823	5	4.186	5	13.296	5
3-6-91	0-10	4.787	5	6.413	5		
3-6-91	10-20	2.126	5	5.022	5		
3-6-91	20-30	1.969	5	4.135	5		
3-6-91	pooled	2.726	5	4.907	5	9.325	5
4-8-91	0-10	4.116	5	4.052	5		
4-8-91	10-20	2.333	5	4.895	5		
4-8-91	20-30	2.008	5	6.030	5		
4-8-91	pooled	2.771	5	4.569	5	11.128	5
4-25-91	0-10	3.264	5	3.326	5		
4-25-91	10-20	3.521	5	5.192	5		
4-25-91	20-30	2.910	5	6.477	5		
4-25-91	pooled	3.172	5	4.137	5	9.980	5
5-14-91	0-10	8.236	10	5.645	10		
5-14-91	10-20	3.199	9	3.568	10		
5-14-91	20-30	7.208	8	4.139	9		
5-14-91	pooled	5.652	10	4.200	10	8.082	10

Appendix G Mean percent of substrate passing a 0.85 mm sieve by date and reach, Poverty Flat, 1990-1991.

DATE	REACH	STRATA	SURROUNDING	N	ARTIFICIAL W/O EGGS	N	INTRUSION	N
10-23-90	2	0-10	0.090	2	0.056	2		
10-23-90	2	10-20	0.164	2	0.044	2		
10-23-90	2	20-30	0.131	2	0.034	2		
10-23-90	2	pooled	0.116	2	0.047	2	0.056	2
10-23-90	3	0-10	0.077	3	0.070	3		
10-23-90	3	10-20	0.099	3	0.044	3		
10-23-90	3	20-30	0.110	3	0.046	3		
10-23-90	3	pooled	0.091	3	0.055	3	0.011	3
3-6-91	2	0-10	0.086	2	0.038	2		
3-6-91	2	10-20	0.120	2	0.068	2		
3-6-91	2	20-30	0.191	2	0.049	2		
3-6-91	2	pooled	0.118	2	0.051	2	0.093	2
3-6-91	3	0-10	0.091	3	0.039	3		
3-6-91	3	10-20	0.152	3	0.057	3		
3-6-91	3	20-30	0.117	3	0.078	3		
3-6-91	3	pooled	0.115	3	0.056	3	0.057	3
4-8-91	2	0-10	0.119	3	0.067	3		
4-8-91	2	10-20	0.154	3	0.077	3		
4-8-91	2	20-30	0.174	3	0.048	3		
4-8-91	2	pooled	0.141	3	0.063	3	0.053	3
4-8-91	3	0-10	0.095	2	0.078	2		
4-8-91	3	10-20	0.126	2	0.073	2		
4-8-91	3	20-30	0.109	2	0.070	2		
4-8-91	3	pooled	0.110	2	0.073	2	0.042	2
4-25-91	2	0-10	0.109	3	0.068	3		
4-25-91	2	10-20	0.098	3	0.055	3		
4-25-91	2	20-30	0.102	3	0.050	3		
4-25-91	2	pooled	0.103	3	0.058	3	0.065	3
4-25-91	3	0-10	0.111	2	0.073	2		
4-25-91	3	10-20	0.087	2	0.046	2		
4-25-91	3	20-30	0.145	2	0.063	2		
4-25-91	3	pooled	0.106	2	0.061	2	0.026	2
5-14-91	1	0-10	0.073	10	0.058	10		
5-14-91	1	10-20	0.108	9	0.075	10		
5-14-91	1	20-30	0.072	8	0.060	9		
5-14-91	1	pooled	0.084	10	0.063	10	0.090	10

Appendix H Mean geometric mean by date and reach
Poverty Flat, 1990-1991.

DATE	REACH	STRATA	SURROUNDING	N	ARTIFICIAL W/O EGGS	N	INTRUSION	N
10-23-90	2	0-10	14.132	2	12.622	2		
10-23-90	2	10-20	5.866	2	12.714	2		
10-23-90	2	20-30	9.009	2	14.309	2		
10-23-90	2	pooled	10.587	2	10.975	2	18.829	2
10-23-90	3	0-10	15.440	3	10.509	3		
10-23-90	3	10-20	10.546	3	17.806	3		
10-23-90	3	20-30	8.584	3	18.089	3		
10-23-90	3	pooled	11.863	3	13.233	3	25.678	3
3-6-91	2	0-10	12.989	2	14.596	2		
3-6-91	2	10-20	9.182	2	11.269	2		
3-6-91	2	20-30	4.956	2	15.129	2		
3-6-91	2	pooled	9.337	2	13.648	2	15.402	2
3-6-91	3	0-10	13.900	3	14.319	3		
3-6-91	3	10-20	6.582	3	13.941	3		
3-6-91	3	20-30	9.300	3	11.749	3		
3-6-91	3	pooled	10.181	3	13.379	3	19.351	3
4-8-91	2	0-10	10.203	3	10.903	3		
4-8-91	2	10-20	8.437	3	11.434	3		
4-8-91	2	20-30	5.448	3	14.769	3		
4-8-91	2	pooled	8.594	3	12.099	3	18.563	3
4-8-91	3	0-10	13.547	2	10.880	2		
4-8-91	3	10-20	8.567	2	12.278	2		
4-8-91	3	20-30	8.815	2	15.190	2		
4-8-91	3	pooled	10.359	2	12.721	2	21.624	2
4-25-91	2	0-10	9.442	3	8.953	3		
4-25-91	2	10-20	10.256	3	11.784	3		
4-25-91	2	20-30	10.766	3	17.076	3		
4-25-91	2	pooled	9.946	3	11.931	3	15.293	3
4-25-91	3	0-10	10.250	2	8.063	2		
4-25-91	3	10-20	11.464	2	15.977	2		
4-25-91	3	20-30	7.087	2	15.901	2		
4-25-91	3	pooled	10.066	2	12.603	2	22.327	2
5-14-91	1	0-10	16.341	10	13.173	10		
5-14-91	1	10-20	9.433	9	9.556	10		
5-14-91	1	20-30	14.872	8	11.036	9		
5-14-91	1	pooled	13.433	10	11.136	10	15.796	10

Appendix I Mean Fredle indices by date and reach
Poverty Flat, 1990-1991.

DATE	REACH	STRATA	SURROUNDING	N	ARTIFICIAL W/O EGGS	N	INTRUSION	N
10-23-90	2	0-10	4.940	2	4.257	2		
10-23-90	2	10-20	1.491	2	4.367	2		
10-23-90	2	20-30	2.793	2	5.208	2		
10-23-90	2	pooled	2.970	2	3.705	2	10.153	2
10-23-90	3	0-10	6.938	3	3.514	3		
10-23-90	3	10-20	4.036	3	7.591	3		
10-23-90	3	20-30	2.553	3	7.891	3		
10-23-90	3	pooled	4.392	3	4.506	3	15.391	3
3-6-91	2	0-10	4.247	2	6.984	2		
3-6-91	2	10-20	2.877	2	5.695	2		
3-6-91	2	20-30	1.192	2	5.881	2		
3-6-91	2	pooled	2.610	2	5.684	2	7.690	2
3-6-91	3	0-10	5.148	3	6.032	3		
3-6-91	3	10-20	1.625	3	4.574	3		
3-6-91	3	20-30	2.487	3	2.970	3		
3-6-91	3	pooled	2.802	3	4.389	3	10.414	3
4-8-91	2	0-10	3.389	3	4.493	3		
4-8-91	2	10-20	2.276	3	5.480	3		
4-8-91	2	20-30	1.611	3	5.547	3		
4-8-91	2	pooled	2.439	3	4.845	3	10.451	3
4-8-91	3	0-10	5.207	2	3.391	2		
4-8-91	3	10-20	2.419	2	4.018	2		
4-8-91	3	20-30	2.603	2	6.755	2		
4-8-91	3	pooled	3.268	2	4.155	2	12.144	2
4-25-91	2	0-10	3.297	3	3.646	3		
4-25-91	2	10-20	3.359	3	4.365	3		
4-25-91	2	20-30	3.566	3	7.493	3		
4-25-91	2	pooled	3.303	3	4.274	3	8.234	3
4-25-91	3	0-10	3.214	2	2.845	2		
4-25-91	3	10-20	3.765	2	6.433	2		
4-25-91	3	20-30	1.926	2	4.954	2		
4-25-91	3	pooled	2.977	2	3.932	2	12.600	2
5-14-91	2	0-10	8.236	10	5.645	10		
5-14-91	2	10-20	3.199	9	3.568	10		
5-14-91	2	20-30	7.208	8	4.139	9		
5-14-91	2	pooled	5.652	10	4.200	10	8.082	10

EMBEDDEDNESS VERSUS INTERSTITIAL VOLUME

INTRODUCTION

Embeddedness measurements have been used for many years in Idaho streams as an index of the degree to which interstitial spaces in the channel substrate are filled with fine sediment. Increased stream sediment caused by soil disturbing activities fills in the interstitial spaces, which are important for juvenile salmonid overwintering and holding cover and as habitat for macroinvertebrate fauna. Cobble embeddedness measurements are expressed as the percent by which predominately larger particles (4.5 to 30.0cm diameter) are surrounded by fine sediment (<6.35mm diameter). The Idaho Water Quality Bureau of the Division of Environment has considered adopting a water quality standard or in-stream standard for cobble embeddedness (Harvey 1988).

OBJECTIVES

The purpose of this experiment was to determine the relationship between a standard measure of cobble embeddedness and substrate interstitial volumes. In other words, to determine if cobble embeddedness is a valid index of interstitial space or changes in interstitial space in stream substrate. The percent cobble embeddedness is calculated as the sum of all vertical lengths of the individual rocks exposed above the embedded plane divided by the sum of the total vertical lengths for all the individual rocks in the sample times 100.

METHODS

Measurement of interstitial volumes in a natural stream environment with any degree of accuracy is extremely difficult and expensive. Rigid boundaries around the substrate column to be sampled would be difficult to construct in what are often turbulent flow conditions and would greatly disrupt the substrate. We chose to try to duplicate stream substrate conditions in a controlled laboratory environment in a manner where both cobble embeddedness and interstitial volumes could be accurately measured.

A wooden box (60cm x 60cm x 60cm) was constructed to contain various size mixes of substrate. One vertical side was plexiglass to allow viewing of the substrate along one vertical plane and to allow vertical measurements of individual rock location, vertical height, and the height to which particles were embedded.

Two different mixes of substrate size classes were used in this experiment (Table 1). Embeddeness versus interstitial volumes were determined for 3 replications within each substrate mixture. Three diameter size classes of particles were used in preparing each mixture: 10-30cm, 6.35-10cm, and 4.5-6.35cm. Mixture #1 was based on the average distribution of the three diameter classes (by weight) in 10 randomly selected 60cm diameter "hoops" in Cow Creek on the Idaho Panhandle National Forest. This mix of substrate represents material typical of steep, flashy granitic systems and the size distribution is skewed toward larger material. The size distribution for mixture #2 was arbitrarily determined to represent a preponderance of the smaller size classes.

Table 1. The size distribution of particle diameters used for the two mixtures of substrate.

	Particle Diameter		
	10-30cm	6.35-10cm	4.5-6.35cm
	-----------% by weight------------		
Mixture #1	85	11	4
Mixture #2	61	29	10

The box was filled about 3/4's full of the substrate mixture. Following each embeddedness vs interstitial volume series of measurements (one run) the substrate was mixed and placed back in the box.

In this experiment we used the water level as a surrogate for the plane of embeddedness that, in a natural stream, would be caused by predominantely fine sediments. To determine a depth versus volume relationship, 2 liters of water were incrementally added and each water depth was measured and recorded. Thus, for any change in depth we can determine the corresponding change in interstitial volume. This is valid until the water plane rises to a point where some of the particles on the surface become submerged. At and above this depth, changes in volumes are not a direct measure of interstitial space.

Once the depth versus volume relationship was measured, the water was drained. Starting at the top of the substrate mix the distance from the top of the box to the top of each particle and the total vertical length for each rock were measured. Measured particals were removed and additional measurements were made on all the particles within the box. By knowing the vertical location of each particle and its vertical length, embeddedness can be calculated for any embedded plane (depth of water). Embeddedness can then be related to interstitial volume, or a change in embeddedness to a change in interstitial volume. Embeddeness and volume were determined at each 1cm depth interval, starting at a depth of 8cm.

Additional measurements and calculations were made to determine the number of free matrix particles, the percentage of free matrix particles, and the areal percentage of water in the horizontal plane. The areal percentage of water in the horizontal plane would be represented by the areal percentage of surface fines in the natural stream environment, assumming all the material embeddeding the cobbles are fines (<6.35mm diameter). Living space was also determined and this is defined as the sum of all vertical heights of particles above the embedded plane (Skille and King 1989). This parameter is similar to the "Interstitial Space Index" proposed by Krammer (1989), except that it is not weighted by sample area.

RESULTS

Figures 1A and 1B illustrate the volume, percent free matrix particles, percent embeddedness and living space for incremental changes (1cm) in the location of the embedded plane (water level height). Note that for the purpose of displaying these four variables on one graph, living space is divided by 10. The relationship between depth and volume is linear until surface particles become submerged, at which time larger volumes are associated with each additional depth increment. The change in volume represents a change in the interstitial space except near the top of the substrate mixture. Although the slope of the volume curve increases for the top 5-8cm depth, the opposite should occur for interstitial space, since much of the change in volume is associated with space above submerged surface particles.

The rate of change in embeddedness is non-linear over the range of depths. In all cases there was a distinct change in slope at a depth of 20 to 30 cm or within 15 to 20 cm of the substrate surface (as defined by the highest particle). This change in slope was associated with embeddedness values of about 20%. In very clean substrate with embeddedness less than 20%, the rate of increase in embeddedness with an increase in depth of the embedded plane was small. Thus, there could be a large loss of interstitial volume that embeddedness measures would not readily detect within very clean substrates.

Living space decreased with increasing depth of the embedded plane, indicating an inverse relationship with the volume of the filled interstitial spaces. The living space curve is fairly smooth and linear up to the depth when individual surface particles become submerged, at which time the rate of loss of living space with increasing depth begins to diminish.

Direct comparisons between embeddedness and volume and between living space and volume are shown in figures 2 and 3. Since the relationship between depth and volume was approximately linear, these figures support observations made on figures 1A and 1B: that (1) there is a slope break in the embeddedness - volume relationship at a about 20-25% embeddedness, (2) below embeddedness levels of 20-25% large changes in interstitial volumes result in relatively small changes in embeddedness, and (3) living space is more linearly correlated with volume up to embeddedness levels of about 60%.

Although this technique was not able to accurately measure the actual volumetric changes in interstial space once some of the surface particles began to be submerged, embeddedness levels for these embedded plane depths were quite high (about 60%). At these embeddedness levels, nearly complete fry departure may occur (Chapman and McLeod 1987). Thus, the critical range of volumetric change in interstitial space and corresponding changes in embeddedness are below the embedded plane depths where submergence of surface particles affects the volumetric data. Changes in actual interstitial volumes near the surface would be much smaller than shown and this would tend to straigten the volume versus living space curves (figure 2) and the embeddedness versus volume curves (figure 3) near the upper range of depths.

The previous graphs show that there is a relationship between interstitial volume and embeddedness but that the relationship varies over a range of embedded depths. Thus, a measured increase in embeddedness levels in a stream of 20%, for example, is probably a valid index of loss of interstitial volume, although the actual loss in volume would vary depending on the initial embeddedness value. However, we might also evaluate how sensitive embeddedness measurements are to small changes in the depth of the embedded plane. Figures 4A and 4B illustrate the changes in volume, embeddedness and living space associated with 1cm

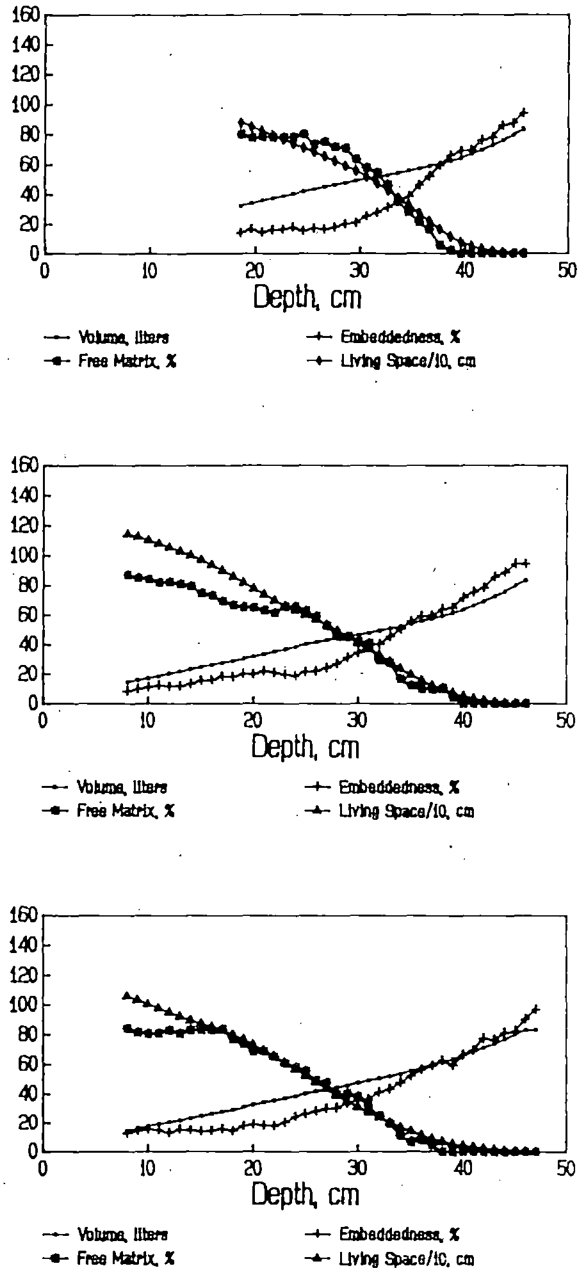

Figure 1A. The relationship between depth of the embedded plane and four substrate variables for substrate mixture #1, runs 1 (top) through three (bottom).

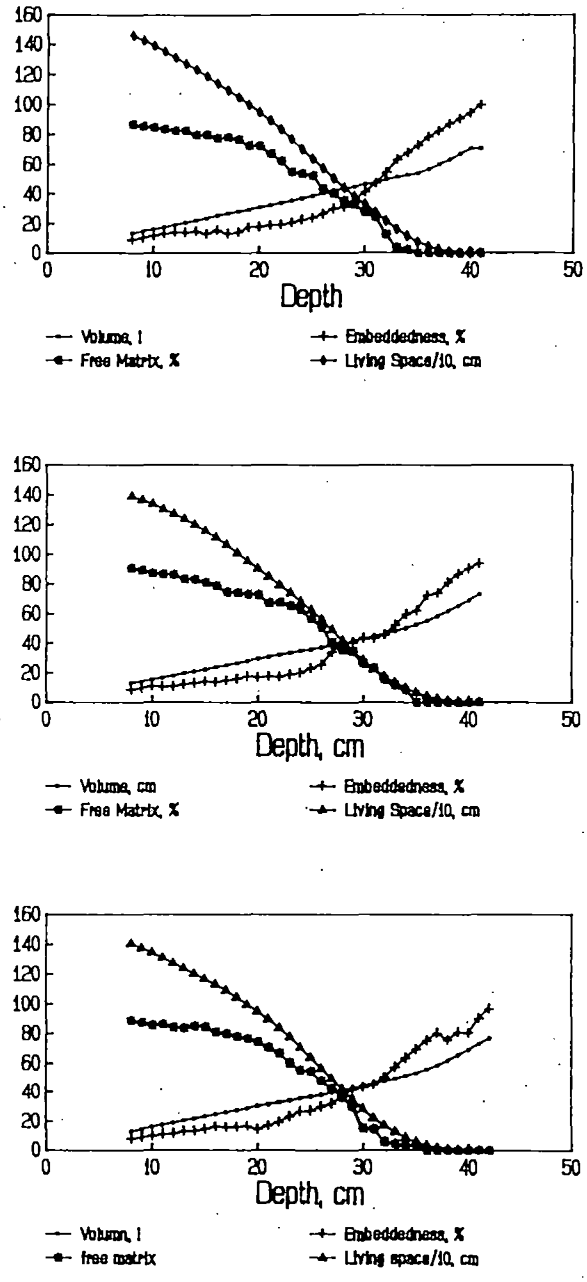

Figure 1B. The relationship between depth of the embedded plane and four substrate variables for substrate mixture #2, runs 4 (top) through six (bottom).

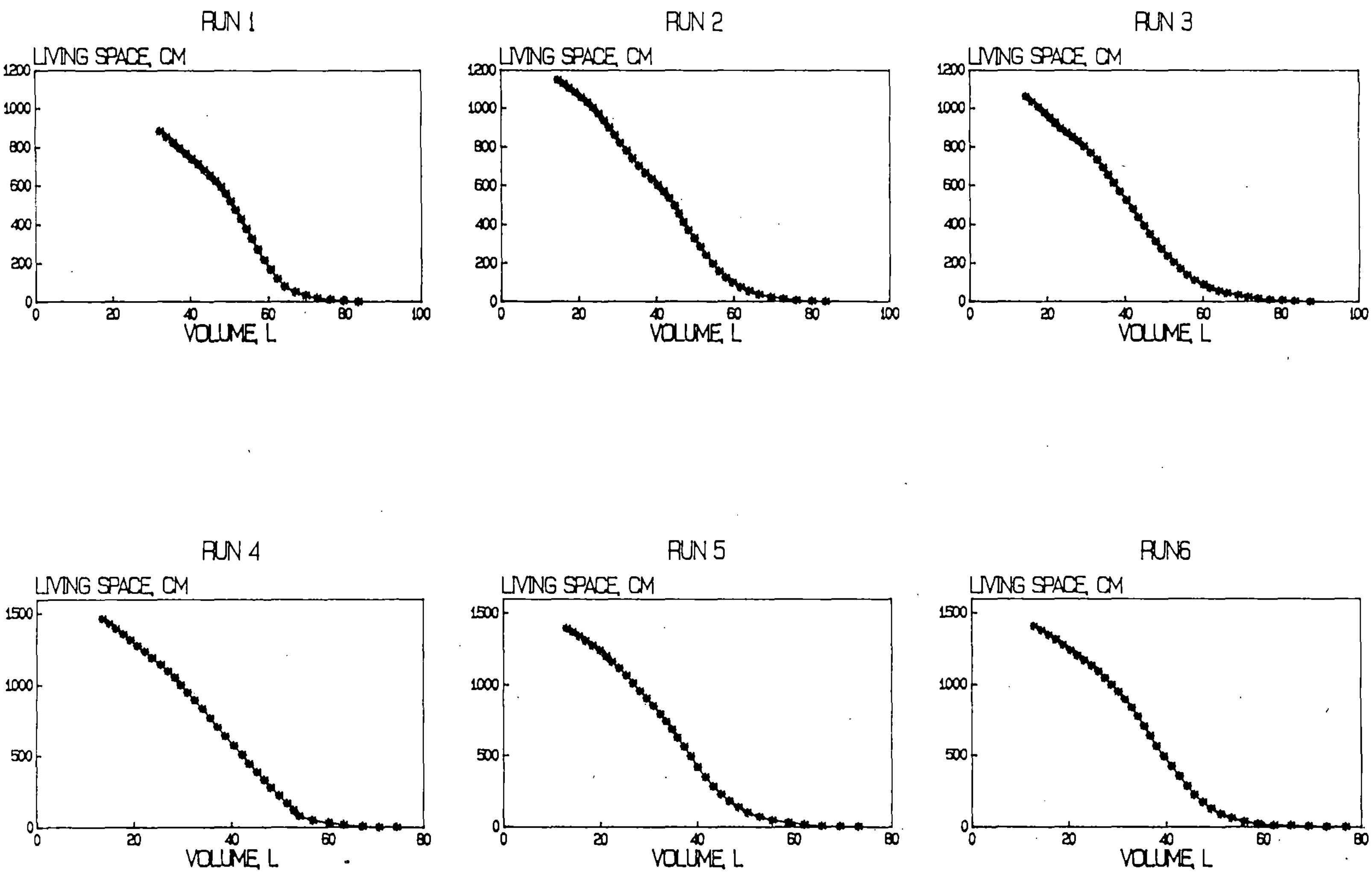

Figure 2. The relationship between volume and living space for the six embeddedness runs.

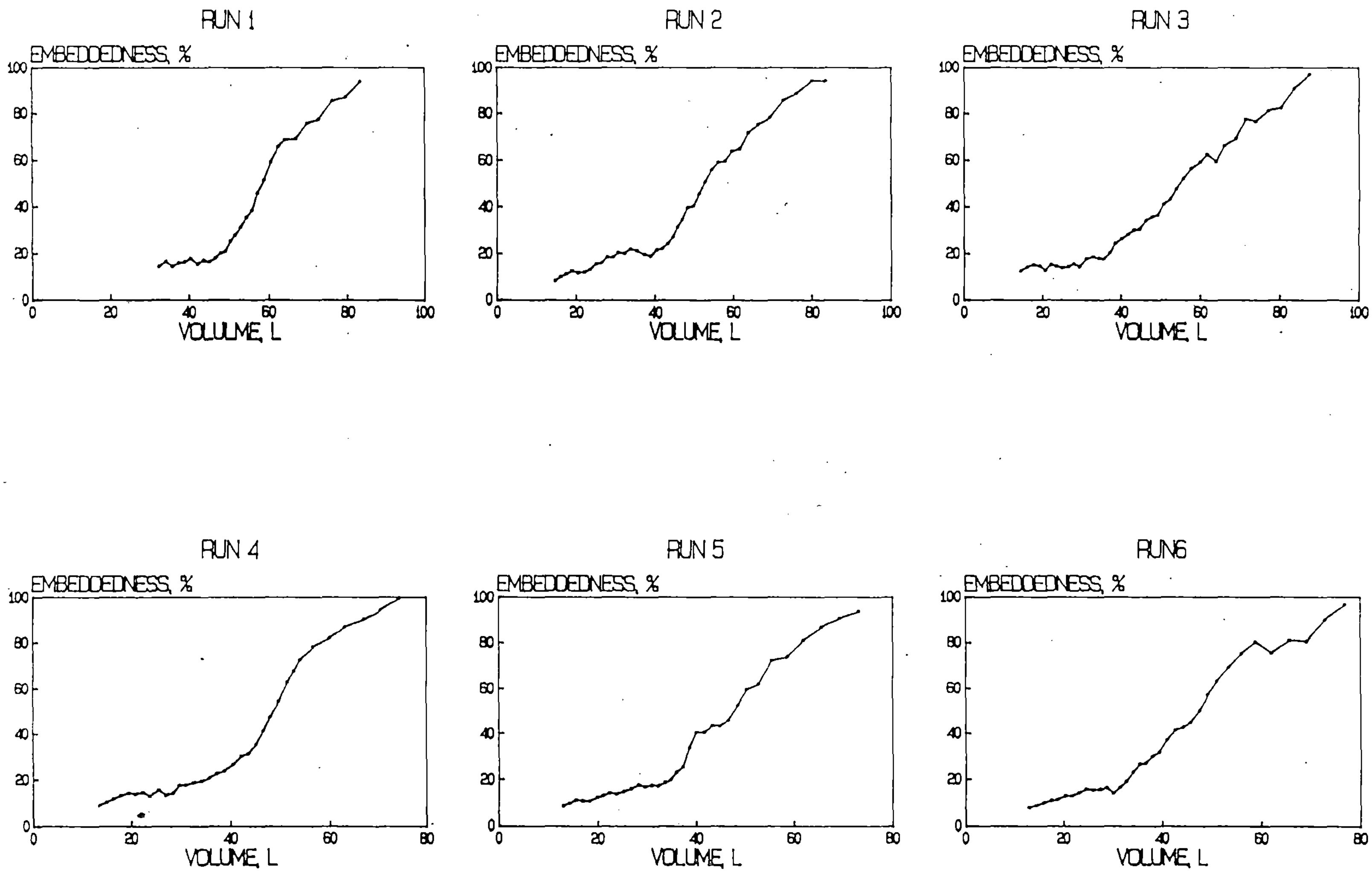

Figure 3. The relationship between volume and percent embeddedness for the six embeddedness runs.

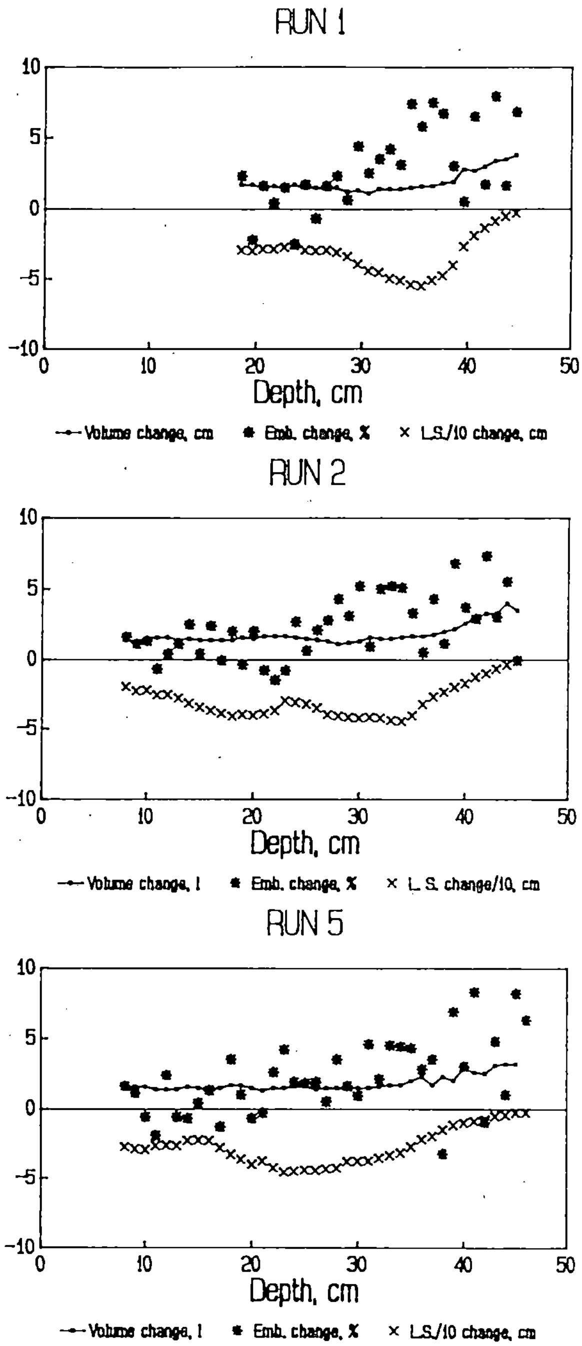

Figure 4A. The change in embeddedness, volume, and living space associated with a 1cm change in depth of the embedded plane over a range of depths for substrate mixture #1, runs 1 to 3.

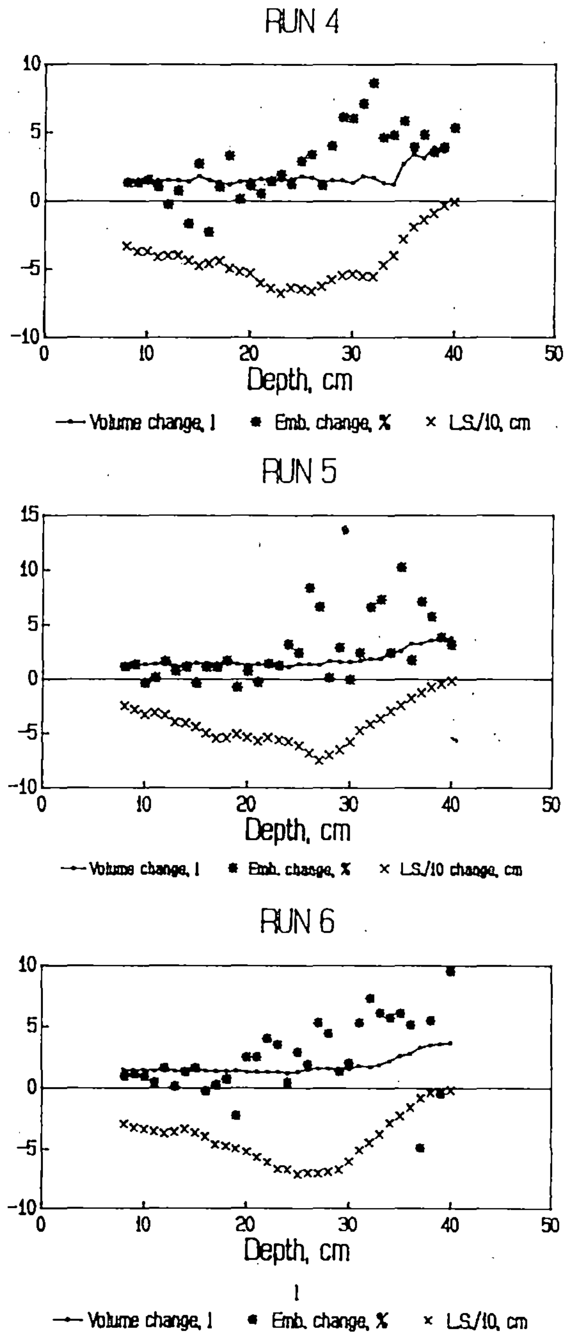

Figure 4B. The change in embeddedness, volume, and living space associated with a 1cm change in the depth of the embedded plane over a range of depths for substrate mixture #2, runs 4 to 6.

increases in the depth of the embedded plane. Changes in volume are very constant over a wide range of depth and increase slightly at the upper range of depth. This change in volume represents the volume of water added to increase the depth 1 cm and thus is a loss in interstitial space. Embeddedness changes are very erratic and often can be negative for small incremental increases in the depth of the embedded plane. Most negative changes in embeddedness were associated with very clean substrate , i.e. low depths of the embedded plane. The general trend is for larger increases in embeddedness with increasing depth of the embedded plane. Living space changes were much less erratic than embeddedness changes over the entire range of depth. Living space changes approach zero once the upper particles begin to be submerged.

Percent surface fines has also been suggested as a measurement of substrate quality. Figure 5 shows the relationships between areal percentage of water surface in the horizontal plane, a surrogate measure of percent fines, and depth of the embedded plane. Up to depths of 30 to 40cm or up to embeddedness levels of about 50%, the percentage of fines stays fairly constant. Thus, a change in depth of the embedded plane would not readily be detected by measuring the percentage of surface fines until the embeddedness levels exceed 50%. Additionally, although the areal percentage of fines is 35-45% at depths below 30-40cm, no fines may be noticeable when viewed from the top of the substrate. Thus, there may be a depth at which a small increase in the depth of the embedded plane may result in a substantial increase in the percent fines, as viewed from the top of the substrate, from near zero to over 40%. Above an embeddedness of about 50%, the rate of change of percent fines with increasing depth is fairly steep and linear, although rather erratic for several of the individual runs. On several of the individual runs, decreases in the percentage of fines occurred with increasing depths over small increments of increasing depth.

SUMMARY

1. There is a general trend of increasing embeddedness with decreasing interstitial volume, although the slope of this relationship for low embeddedness values is such that a large loss in volume is not reflected by measureable increases in embeddedness.

2. Increases in the depth of the embedded plane are not always associated with increases in embeddedness and decreases in embeddedness are possible. This is due to how embeddedness is measured and the fact that it is expressed as a percentage. Since there was considerable scatter in the embeddedness change versus depth change relationship, this implies that large sample sizes are needed to obtain true values of embeddedness with any degree of confidence.

3. Living space was more linearly related to interstitial volume than was embeddedness, until surface particles began to be submerged. This was much less scatter in the volume change versus living space change relationship and a loss of interstitial volume was always associated with a loss of living space. This index is sensitive to small changes in the depth of the embedded plane and would require fewer samples to account for any variation in the relationship (as compared to the embeddedness versus depth of the embedded plane relationship). Living space can be calculated from the measurements made to determine embeddedness. Thus, past stream evaluations using cobble embeddedness are still usefull, in that with some recalculation of the data, living space could be determined.

4. Percent surface fines is positively correlated with increasing depth of the embedded plane (a loss in interstitial volume) above corresponding

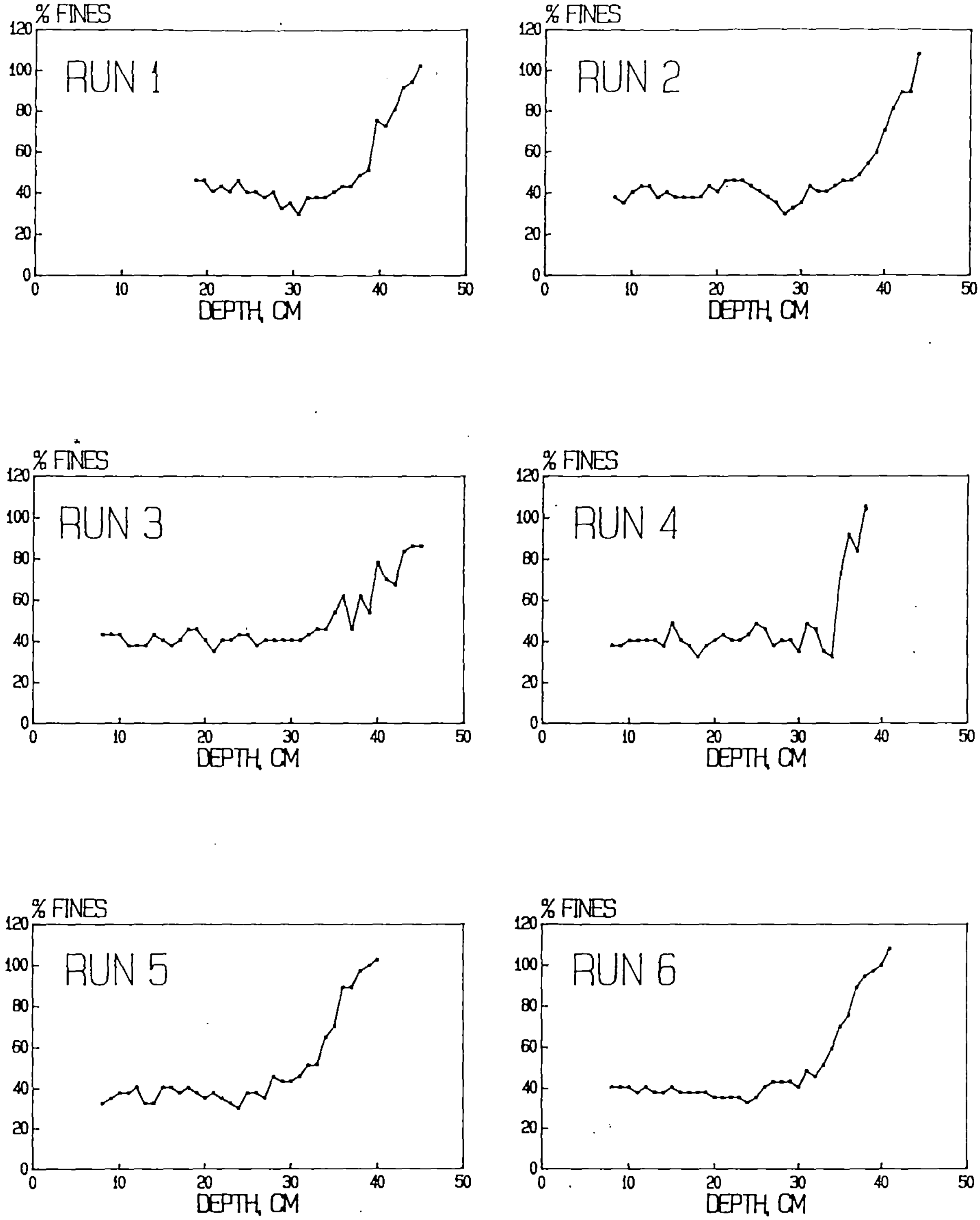

Figure 5. The relationship between the percentage of fines and depth of the embedded plane for both substrate mixtures #1 (runs 1-3) and #2 (runs 4-6).

embeddedness values of about 50%. Although for small increases in the depth of the embedded plane, negative changes in percent surface fines are possible. For clean substrate with low embeddedness, percent surface fines would not be a responsive parameter to loss in interstitial volume.

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